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WORKING PAPER 140

Inventory of Water Storage Types in the Blue Nile and Volta River Basins

Robyn Johnston and Matthew McCartney

With contributions from (in alphabetical order):
Barnabas Amisigo, Felix Asante, Seleshi Awulachew, Fiseha Behulu, Samuel Dagalo, Fikadu Fetene, Gerald Forkour, Eric Sarpong Owusu, Kassa Tadele, Tarekegn Tadesse and Wondmagegn Yazea

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Contents

Summary

For agriculture there is a continuum of water storage options, ranging from groundwater aquifers, soil water, natural wetlands and small ponds and tanks to large reservoirs. In any specific situation each of these has its own niche in terms of technical feasibility, socioeconomic sustainability and impact on public health and the environment. Planning storage requires not only insight into impending needs but also a good understanding of what already exists and what was, and was not, successful, in the past. This paper provides an inventory of existing and prospective water storage in the Ghanaian Volta and the Ethiopian Blue Nile basins. For both, it is believed to be the first attempt to draw together information on the full spectrum of storage types into a single document. Based on published and gray literature it provides as much quantitative data as possible, and highlights both the dearth of readily available information and the lack of integrated planning of storage in both basins. Recommendations are made for improved planning in future.

INTRODUCTION

Throughout sub-Saharan Africa, existing climate variability and insufficient capacity to manage that variability lie behind much of the prevailing poverty and food insecurity. Some 200 million people are food insecure, largely because they depend on unreliable rain-fed agriculture (Ward et al. 2007). Similarly, national economies, highly dependent on rain-fed agricultural production, are exceedingly vulnerable to seasonal fluctuations in climate. Against this background, water storage is widely regarded as a necessity for poverty alleviation and sustainable socioeconomic development (Grey and Sadoff 2006). As the effects of climate change become more pronounced water storage is also seen as a key contributor to adaptation strategies.

For much of Africa, physical water scarcity is not the most significant limiting factor in access to water. Rather it is economic scarcity that results from lack of investments in water infrastructure (Hanjra et al. 2009). Relatively few large dams have been built (<2,000 of the 45,000 globally) and per capita storage in many African countries is amongst the lowest in the world (IHA 2009). However, for agriculture, water stored in dams is not the only option. Other forms of water storage include groundwater, enhanced soil moisture and small ponds and tanks. Their effectiveness varies, but each of these types provides a buffer during dry periods. Furthermore, each has its own niche in terms of technical feasibility, socioeconomic sustainability, institutional requirements and impact on public health and the environment.

Options other than large dams are often neglected in the planning and management of water resources and there is very little quantitative information on either the extent of these storage types or their relative importance in different parts of sub-Saharan Africa. There is little understanding of the most appropriate types of technology in specific situations and, in particular, whether investment for poverty alleviation is best targeted at large- or small-scale interventions. Furthermore, there has been almost no systematic evaluation of the possible implications of climate change for different storage types, or how they can best contribute to climate change adaptation.

Against this background, this paper provides an inventory of water storage types in the Volta and Nile basins. As far as possible, it provides a quantitative baseline of existing and planned water storage of all types in both basins. It enables comparison between the basins, illustrating similarities as well as differences in basin characteristics, options adopted and approaches to planning and management of water storage. The paper highlights the lack of readily available information on both existing and planned storage in both basins and identifies the need for much more integrated planning, across the range of storage options, in future.

DIFFERENT TYPES OF WATER STORAGE

Water storage can be conceptualized as a continuum of five primary, but overlapping, storage types: natural wetlands, soil moisture, groundwater aquifers, ponds/small tanks, and reservoirs (Figure 1).

Reservoirs

Reservoirs store water impounded behind dams constructed across streams and rivers, ranging from major structures storing billions of cubic meters to small impoundments behind simple earth bunds (Plates 1a, 1b). Large reservoirs are usually defined as those with storage capacity exceeding 3 million cubic meters (Mm^3) (ICOLD 2003). In addition to supplying water for irrigation and

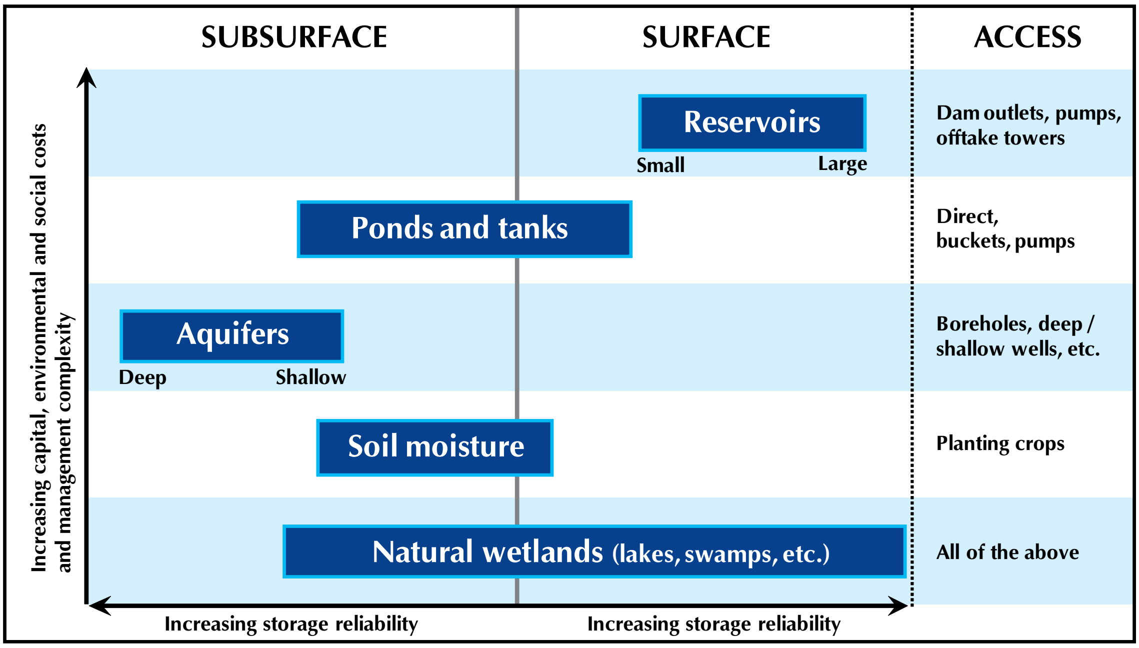


FIGURE 1. Water storage continuum.

domestic supply, many large reservoirs not only supply water for industrial purposes and for the generation of hydropower but are also used for flood control. Some large reservoirs provide storage that is greater than the mean annual runoff and so provide multiyear carryover of water. These can be particularly important where flow varies considerably from year to year, and prolonged dry periods are common.

Small reservoirs are typically formed by constructing simple earth dams. Often, as these dams do not have pipe outlets, water from the reservoir is removed by livestock drinking, pumping and as a consequence of seepage, spilling and evaporation. Since they store relatively low volumes of water, most small reservoirs empty every year. They tend to be shallow, with relatively large surface areas, so that, in common with many ponds/tanks, a significant proportion of the water may be lost through evaporation.

Plate 1a. Large dam/reservoir.

1b. Small dam/reservoir.

In addition to bringing social and economic benefits, dams, particularly large ones, are often associated with costs, particularly for rural riverside communities. These costs result from the need to relocate communities from the area upstream of the dam, inundated by the reservoir, and downstream from disruption of the ecosystem services that rivers naturally provide. Often, it is the poorest in society, lacking the political power and financial resources to mitigate impacts, who gain the least and yet are the most adversely affected by large dams (McCartney and King 2010). Both large and small dams also affect transmission of vector-borne diseases such as malaria and schistosomiasis.

Ponds and Tanks

Ponds and tanks are defined in this paper as off-stream household or community-built water stores filled either by rainwater harvesting, surface runoff or through groundwater infiltration (Plates 2a, 2b). They are generally of limited volume (usually only a few cubic meters) and are most commonly open water stores lined either with rocks and mortise or with polyethylene sheets or geomembranes (to reduce infiltration losses). “Dugouts” which are hand-dug excavations, widespread in northern Ghana and other places in West Africa, are ponds in this classification. A common limitation is that they are usually shallow, with a relatively large surface area, so that a significant proportion of the water is “lost” through evaporation. To reduce evaporation some are covered with metal sheeting or thatched roofs but this adds significantly to the cost.

Plate 2a. Pond/tank without a roof.

2b. Pond/tank with a roof.

Ponds and tanks are used for livestock watering, domestic purposes and sometimes small-scale irrigation. In common with small dams, one major advantage is that they represent a decentralized system that enables individuals and communities to manage their own water for their own purposes (Barron 2009). However, also in common with small dams, there may be adverse public health impacts from vector-borne diseases such as malaria and schistosomiasis (Waktola 2008).

Groundwater

Groundwater is stored in moderately to highly permeable rocks called aquifers (i.e., “water-bearing” rocks). There are two broad types of aquifers: unconfined and confined. An unconfined aquifer is one where the upper surface is not restricted by impervious rocks and so the upper water surface (the water table) is at atmospheric pressure. A confined aquifer is one where the upper surface is overlain by an impervious layer so that the groundwater is confined under pressure, which is significantly greater than atmospheric pressure. The amount of water that can be abstracted from a well in an aquifer is a function of the characteristics (particularly the permeability) of the rock. Some aquifers will yield only a few liters per day, whilst others can yield as much as several million liters.

A major advantage of water storage in aquifers is that there is little or no evaporation and total volumes of groundwater are often much greater than annual recharge. Consequently, groundwater is an important buffer for rural communities throughout Africa. Traditionally, throughout sub-Saharan Africa, it was the accessibility of groundwater through dug-wells (Plate 3a), at springheads and in seepage areas, which controlled the extent of human settlements beyond the major river valleys. Deep drilling and pumping machinery introduced from the 1970s have enabled the area utilizing groundwater to be extended. Today, over very large areas of rural land it is only the presence of successful boreholes equipped with reliable pumps that allow human populations to survive; up to 80% of the rural population of sub-Saharan Africa are reliant on groundwater as their primary or only source of water (Calow and MacDonald 2009) (Plate 3b).

Plate 3a. Hand-dug well.

3b. Pumping from a borehole.

Soil Moisture

Soil moisture refers to the water held between soil particles in the root zone of plants (i.e., the upper 200 cm of the soil profile). Water storage in the soil profile is extremely important for agriculture and supplies water for rain-fed cultivation which makes up 95% of the agriculture in Africa (Giordano 2006). Globally, the total volumes of water stored within the soil are huge, but at any given locality they are relatively small and quickly depleted through evapotranspiration. Because of this, in recent decades there has been increased interest in various in-situ (i.e., in-field) rainwater management techniques that enhance infiltration and water retention in the soil profile. The objective of these is to stabilize and increase crop yields by increasing the effectiveness of rainfall. These are referred to as soil and water conservation (SWC) measures, and include deep tillage, reduced tillage, zero tillage and various types of planting basin, all of which have been successfully used in semiarid regions of Africa (Plates 4a, 4b).

Plate 4a. Terracing.

4b. Planting basins.

Natural Wetlands

Lakes, swamps and other wetlands are sinks, into which surface water or groundwater flows from a surrounding catchment. They are "natural harvesters" of rainwater and are, by definition, sites where water occurs at or close to the ground surface. In arid and semiarid regions, the capacity of wetlands to retain moisture for long periods, sometimes throughout the year and even during droughts, means that they are extremely important for small-scale agriculture and food security. Water is effectively "stored" in different wetland types, and at different times, as groundwater, soil moisture and surface water. Consequently, natural wetlands span the surface/subsurface interface (Figure 1) and they can provide water in many different ways (Plates 5a, 5b). Farmers are often skilled in the management of water within wetlands. For example, throughout West Africa, complex systems have been devised to control not only the frequency and timing of flooding but also the depth and duration of standing water in inland valleys (Wopereis et al. 2009).

Plate 5a. Recession cultivation at edge of Bahi wetland.

5b. Livestock grazing in a wetland.

ETHIOPIAN ABAY (BLUE NILE) BASIN

The Blue Nile rises in the highlands above Lake Tana and flows through the Central Highlands of Ethiopia (where it is known as the Abay) before entering Sudan as al-Bahr al Ashraq and joining the Nile near Khartoum (Figure 2). The Abay part of the basin covers 180,000 km^2, accounts for 20% of Ethiopia's land area and is home to a population of around 19 million (i.e., 28% of the country's population). A detailed description of the basin's characteristics can be found in Awulachew et al. 2008 and Yilma and Awulachew 2009.

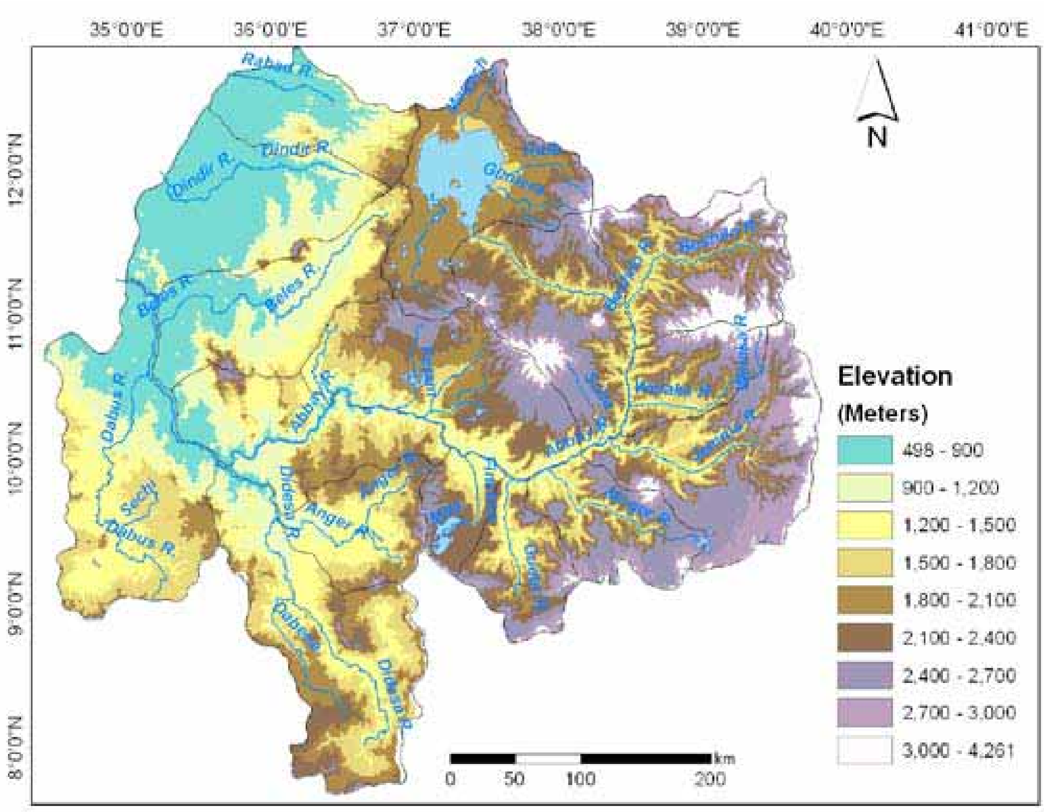


FIGURE 2. Map of the Abay Basin (*Source*: Yilma and Awulachew 2009).

Hydrology and Climate

The Blue Nile contributes 62% of the total Nile flow reaching the Aswan Dam in Egypt. Flow in the Abay River averages approximately 48 billion cubic meters (Bm^3) at the Sudan border, equivalent to average annual runoff from the catchment of 260 mm and a runoff coefficient of approximately 14%. The Abay River is perennial, but more than 80% of annual average runoff occurs in just four months (July-October) with less than 1% in April.

The Abay Basin receives on average 1,535 mm of rainfall, ranging from 800 mm to 2,220 mm and generally increasing with altitude (Figure 3a). Rainfall varies considerably from year to year, with pronounced wetter and drier decadal cycles. The mean annual temperature ranges from 5 to 30 ^{o}C depending on altitude (Yilma and Awulachew 2009). Potential evaporation in the basin generally exceeds rainfall, except in the highlands and increases from around 1,200-1,400 mmy^{-1} in the east to over 2,000 mmy^{-1} in the lowlands in the northwest (Figure 3b). Significant micro-climatic variations reflect the varied topography and other factors (AMU 2009).

In most of the catchment (particularly in the west), about 95% of the annual rainfall occurs in the wet season (May to October). In some years, short rains occur between April and May and in eastern areas, there is a bimodal rainfall pattern with the *belg* (short wet season from mid-February to mid-May) and the *kiremt* (main rainy season from June to September).

(a) (b)

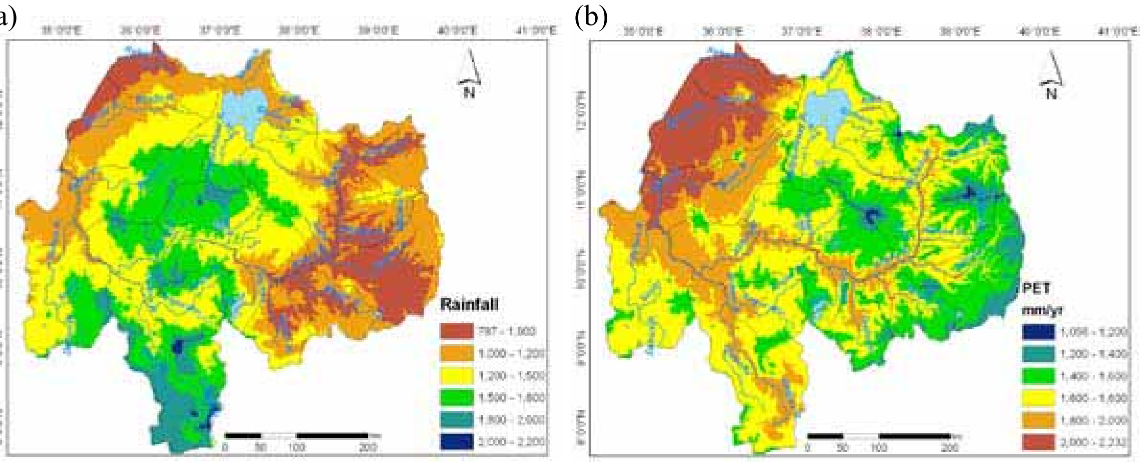


FIGURE 3. (a) Rainfall; and (b) potential evaporation distribution in the Abay Basin (*Source*: Yilma and Awulachew 2009).

There is considerable uncertainty around projections of future rainfall under climate change. Results from Global Climate Models (GCMs) are contradictory; some show increases in rainfall whilst others show decreases. A recent study of 17 GCMs indicated precipitation changes between -15% and +14% which, compounded by the high climatic sensitivity of the basin, translated into changes in annual flow of the Abay at the Sudan border of between -60% and +45% (Elshamy et al. 2008). Other studies have also produced differing results (Kim et al. 2008; Shaka 2008). To date, no studies have been conducted into the possible changes in water demand (e.g., for irrigation) arising from changes in temperature and rainfall in the basin.

Groundwater

Ethiopia has substantial groundwater resources but estimates of the total are inconsistent. The Ministry of Water Resources estimated 2.6 Bm^3 (MoWR 2002) while the Ethiopian Institute of Geological Surveys estimates 6.5 Bm^3.[1] Information regarding groundwater potential, availability and accessibility is lacking and there has been little systematic research on groundwater resources including aquifer delineation, water table depth and recharge volumes. Geologically, the Abay Basin comprises crystalline Precambrian basement (igneous and metamorphic rocks) overlain by Palaeozoic and Mesozoic sediments, Cainozoic volcanic lava flows and Quaternary alluvium on the floodplains of major rivers (Ayenew 2009). The groundwater potential of these geological units varies. Typically, in the Abay the shallow unconfined aquifers (mainly in Quaternary alluvium) have yields less than 2.5 ls^{-1}. Values of 40-80 ls^{-1} are not uncommon from volcanic aquifers, and springs with yields of up to 200 ls^{-1} are reported (Ayenew 2009).

[1]Personal communication.

The depth to the watertable varies. The majority of unconfined aquifers (e.g., below the lowland plains of Benshangul-Gumuz) display shallow groundwater, often less than 20 m, but in some highland volcanic areas depth to static groundwater level may be as much as 100 m. Recharge is estimated to range from a few tens of mmy^{-1} in the northwestern lowlands to 250-400 mmy^{-1} in the highlands. The maximum recharge occurs during the wet season, when groundwater levels may rise by up to 2 meters, though in general the seasonal change in water level is not high. The quality of the groundwater in the highlands is generally good, although most of the groundwater in the volcanics and Mesozoic sediments has a high carbonate content and some salinity. In some urban centers, high nitrate, trace elements and bacteriological pollution are reported (Ayenew 2009).

Land Use

The topography of the basin falls into three main categories: (1) the plateau highlands, with elevations from 2,000 m to 4,230 m, dominate the eastern part of the basin and comprise mainly volcanic soils; (2) the plateau valleys, at the lower end of which the streams fall sharply into deep eroded canyons that ultimately join the main Abay; and (3) lowland plains and eroded hills in the western part of the basin, dropping to 490 m where the Abay crosses the Sudan border.

Rain-fed mixed farming is the main land use in the highlands and plateau valleys in the eastern part of the basin. A wide range of food crops (cereals, pulses, vegetables) are grown, and livestock production is an important component. Woodlands and shrublands used for pastoralism and shifting cultivation of maize and sorghum predominate in the hotter, drier lowlands to the west (Yilma and Awulachew 2009). The average farm size is less than 1 ha, and productivity of all agricultural systems in the basin is low, with reported average productivity between 783 and 1,234 $kgha^{-1}$ in different farming systems in the main growing season (Erkossa et al. 2009).

Importance of Water Storage

Ethiopia has abundant water resources. The per capita renewable water resource exceeds 1,300 m^3y^{-1} nationally, and 2,500 m^3y^{-1} in the Abay Basin.[2] However, as a result of rainfall variability and a lack of infrastructure and institutional arrangements to support and manage water resources much of the country suffers from frequent and severe water shortages (CA 2007). According to World Bank 2006, per capita storage in large reservoirs in Ethiopia is estimated to be about 100 m^3 (c.f. 750 m^3 in South Africa and 6,150 m^3 in North America).

Studies have demonstrated the link between rainfall and national GDP growth in Ethiopia. This is due mainly to the high dependence of the economy on agriculture, which, though fluctuating with seasonal conditions, contributed on average 46% of GDP between 2000 and 2008. The fluctuations undermine the country's ability to sustain economic growth. It is estimated that unmitigated hydrological variability currently costs the economy more than 30% of its growth potential and the development of water storage at all scales has been recommended as an economy-wide priority (World Bank 2006).

[2] Both national and basin figures calculated.

Securing Food Production and Livelihoods

The vast majority of Ethiopia's agriculture is rain-fed and very vulnerable to seasonal water shortages. Even in good years, 75-80% of production is consumed at household level (World Bank 2006), so decreases in yields, crop failure or livestock deaths due to water shortages have serious impacts on food security. Food shortages are distressingly common; 46% of Ethiopia's population is classed as undernourished, and hunger is assessed as "extremely alarming" (von Grebmer et al. 2008).

Irrigation

Despite significant potential, irrigation is not widely used in Ethiopia and generates less than 3% of national food production. A national irrigation inventory identified 791 schemes throughout Ethiopia with a total area of 0.107 Mha (Awulachew et al. 2007), but only about 70% of schemes are operating at close to design capacity (Mackenzie Consultants 2010).

FAO reported a total of 47,020 ha of irrigation in the Abay Basin in 2001 with at least 32 small and 3 medium irrigation schemes (FAO 2005a). The largest scheme in the basin (ca. 8,000 ha) is used for sugarcane. Some irrigated vegetables and fruit trees are grown in medium- and large-scale schemes. However, there are also a large number of small schemes in the Amhara and Oromia states, some of which are located in the basin (Awulachew et al. 2007). Cereals, pulses, vegetables, and fruit are the main crops in small-scale schemes. The majority of irrigation in the basin is supplied directly from rivers, by diversion, gravity-fed systems, or pumping. Of 1,688 documented agricultural water management interventions in the Amhara region, over 90% were simple river diversions (Gebregziabher 2010) and so unprotected from seasonal and interannual variation in water availability.

Irrigation development is considered a cornerstone of the food security and poverty reduction strategies in the country, and an important tool to stimulate economic growth and rural development. Access to irrigation can substantially reduce risk and increase farmer incomes. A survey of 1,024 households in four states in Ethiopia (including Oromia) found that irrigation generates an average income of approximately \$323[3] ha^{-1} under smallholder-managed irrigation systems compared to an average income of \$147 ha^{-1} for rain-fed systems. The gross margin from medium- and large-scale systems was calculated to be \$400 ha^{-1} and \$1,308 ha^{-1}, respectively (Hagos et al. 2009). The same study estimated that irrigation contributed 5.7% and 2.5% to agricultural GDP and the overall GDP, respectively, in 2005/06 and that this could rise significantly if proposed development takes place.

Nationally, potential irrigable area is around 3.73 Mha (Awulachew et al. 2007). Under the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) the government planned to expand irrigated areas across Ethiopia by more than 0.5 Mha by 2010 through the implementation of a range of small-, medium- and large-scale schemes (MoFED 2006). It is believed that approximately 50% of this target has been achieved (Awulachew pers. comm.). Currently, the Government of Ethiopia aims to increase irrigated area to 1.5 Mha by 2015, predominantly through the implementation of small-scale and rainwater harvesting schemes (1.24 Mha) and also with some medium- and large-scale schemes (0.28 Mha). A total of 815,581 ha of irrigation potential has been identified in the Abay Basin in 90 small-scale projects and 121 medium and large projects

[3] In this paper, \$=US\$.

(Figure 4) (including areas in the Dinder and Rahad river catchments) but only a relatively small proportion is likely to be developed in the immediate future (see below).

Hydropower

Around 96% of Ethiopia's electricity generation is from hydropower, with a total generating capacity of 814 MW (EEPCo 2009). Two of Ethiopia's eight hydropower plants are located in the Abay Basin at Tis Abay and Finchaa, with a combined generating capacity of 218 MW. A third power station (460 MW), which will utilize water diverted from Lake Tana to the Beles River, is on the point of starting operations. When it does so, the Tis Abay power station will be mothballed and only used in emergencies (McCartney et al. 2010). Throughout the country only about 15% of the population has access to electricity; most rely on biomass and fuelwood (IEA 2009). Because of the heavy dependence on hydropower, interruption of power supplies is common during droughts. In 2009, high demand, in combination with drought, caused power interruptions that lasted for about 4 months, with very severe disruptions throughout the country and grave economic implications. The total national exploitable hydropower potential is estimated to be approximately 30,000 MW (162,000 GWh y^{-1}), with many of the proposed projects within the Abay Basin (Beyene and Abebe 2006). Expansion of hydropower could assure domestic supplies and provide much needed export income.

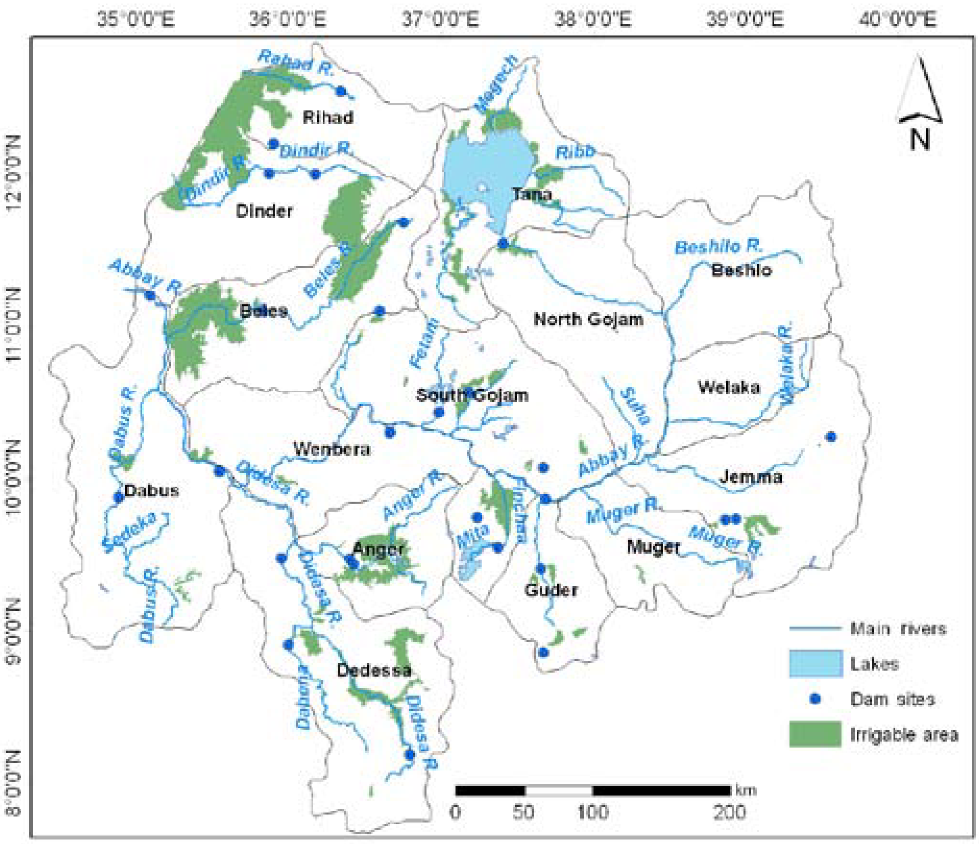


FIGURE 4. Proposed irrigation and dam sites in Abay Basin (*Source*: Yilma and Awulachew 2009).

Domestic and Industrial Water Supply

Access to improved water supplies in Ethiopia is low overall (38%), with excellent coverage in urban areas (98%) but very low access in rural areas (26%) (WHO-UNICEF 2010). Almost 25% of water installations in rural areas are not functional at any given time (UN Water 2006). Incidence of waterborne diseases is high; diarrhoea accounts for 46% of the under-five child mortality and almost two thirds of people living in rural areas have to fetch water from a source within a distance of 1 km, or even further in dry periods (UN Water 2006). Water supplies for industry are drawn almost entirely from groundwater; most large industries have their own boreholes (AMU 2009).

INVENTORY OF CURRENT AND PLANNED STORAGE IN THE ABAY BASIN

Large and Medium Reservoirs

Current

There are currently three large reservoirs in the Abay Basin, built for hydropower and irrigation (Table 1). Around 8,000 ha of sugarcane are irrigated from the Finchaa Reservoir and approximately 6,000 ha of mixed crops will soon be irrigated from the Koga Reservoir, which became operational in 2008. Recession cropping, mainly for maize and rice, is carried out in the wetlands adjacent to the lakeshore of Lake Tana. Seven small schemes, with a total area of around 75 ha, pump from the lake, but currently there are no large irrigation schemes drawing water from the lake (Awulachew et al. 2007).

TABLE 1. Existing large dams in the Abay River Basin.

Dam	River	Storage (Mm^3)	Built	Purpose
Chara Chara	Abay	9,100*	2000	Regulation of Lake Tana outflows for hydropower production at Tis Abay I and Tis Abay II power stations (installed capacity – 84 MW); around 75 ha of irrigation drawn directly from the lake.
Finchaa**	Finchaa	2,395	1971	Regulation for hydropower production (installed capacity 134 MW) and also sugarcane irrigation (8,145 ha).
Koga	Koga	81.3	2008	Regulation of the Koga River for smallholder irrigation (6,000 ha).

Source: McCartney et al. 2009.

* This is the active storage of Lake Tana controlled by the operation of the weir (i.e., lake levels between 1,784 and 1,787 masl). It represents 2-4 times the average annual outflow of the lake.

** A small dam located on the Amerty River (storage 40 Mm^3) diverts water from the river to the Finchaa Reservoir.

Planned

The Abay Basin has very significant potential for the development of both hydropower and large-scale irrigation, and a number of large reservoirs have been proposed to provide water for these (BCEOM 1998; Table 2; Figure 5). In storage terms, the most significant development is a cascade of four very large hydropower dams proposed on the Abay mainstream at Karadobi, Mabil, Mandaya and Border with a total generating capacity of 5,820 MW and storage over

84 Bm³ (i.e., 170% of the mean annual flow at the border). These proposed dams are located within the deep gorge of the Abay River, and have no significant areas of irrigable land close-by. A number of other hydropower schemes, some of which also include significant irrigation components, are proposed throughout the basin.

Development of large-scale irrigation in the basin is proposed as multipurpose use of hydropower reservoirs, from smaller purpose-built irrigation reservoirs, and from interbasin transfers. A total irrigation command area of 395,000 ha could be commissioned over the next 20-40 years (Table 2). If all planned large and medium dams are constructed, the total large reservoir storage in the Abay Basin is estimated to increase to 167 Mm³ (i.e., 360% of the mean annual flow at the border) in the long term (McCartney et al. 2009).

The proposed schemes could provide many substantial benefits in terms of hydropower and irrigation. However, they could also have adverse impacts on local livelihoods and ecology. For example, full development of the Lake Tana Subbasin would provide on average 2,207 GWhy^{-1} of power, and 548 Mm^{3}y^{-1} of water for irrigation. However, the mean annual water level of the lake would be lowered by 0.44 m with a consequent decrease of 30 km^2 in the average surface area of the lake and much greater declines in some years. Besides having adverse ecological impacts, this would also have significant implications for shipping and the livelihoods of many local people (McCartney et al. 2010).

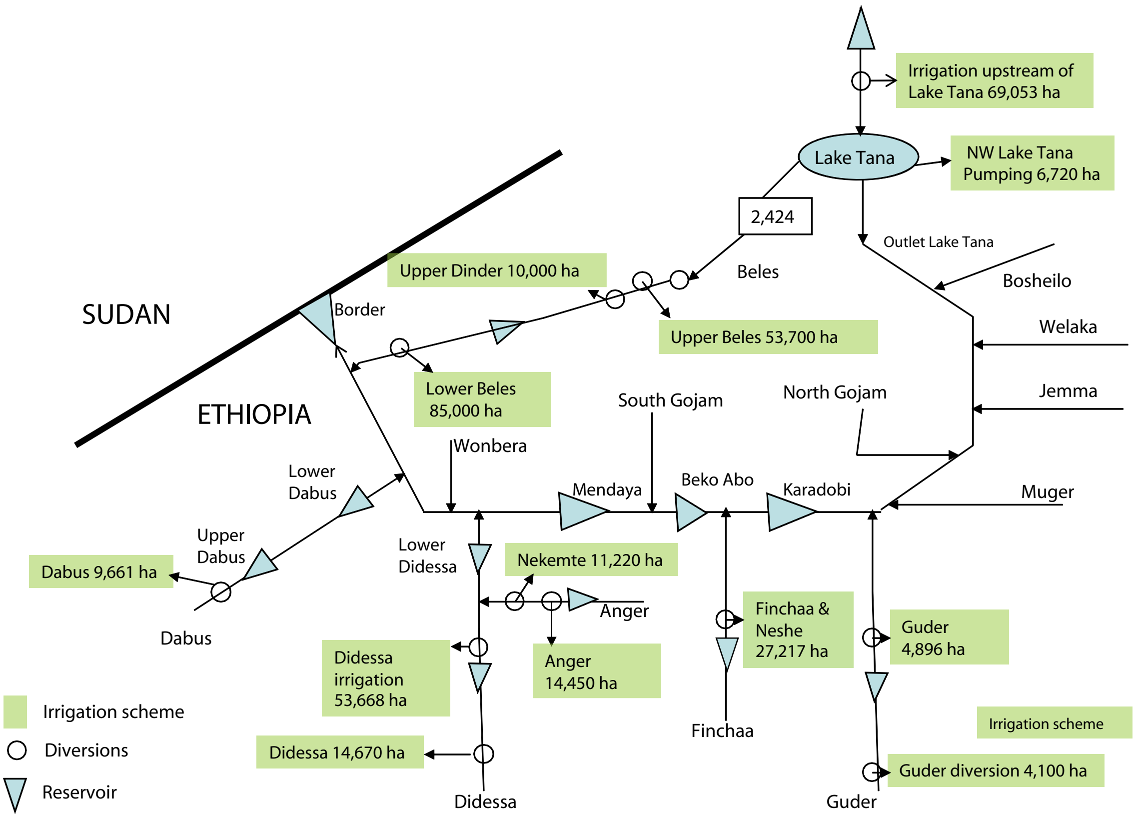


FIGURE 5. Schematic of proposed large-scale storage and irrigation schemes in the Abay Basin that could be implemented over the next 20-40 years (*Source:* adapted from McCartney et al. 2009).

TABLE 2. Proposed water resource development in the Blue Nile River Basin (*Source*: McCartney et al. 2009).

Scheme	Subbasin	Description
Tana-Beles transfer	Tana and Beles	Transfer of water from Lake Tana to Beles catchment for hydropower production and irrigation. Hydropower capacity: 219 MW Average annual transfer: 2,424 Mm^3
Anger irrigation and hydropower scheme	Anger	Maximum irrigated area: 14,450 ha Average annual demand: 202 Mm^3 Hydropower capacity: 1.8–9.6 MW
Irrigation in the Lake Tana Subbasin	Lake Tana	Dams to be constructed on the major inflows to Lake Tana (i.e., Megech, Ribb, Gumara and Gilgel Abay). Total storage: 1,028 Mm^3 Irrigation area: 61,853 ha Average annual demand: 516 Mm^3
Arjo irrigation and hydropower scheme	Didessa	Arjo scheme: 13,665 ha Average annual demand: 92.1 Mm^3 Hydropower capacity: 33 MW
Irrigation in the Beles Subbasin	Beles	Upper Beles scheme: 53,700 ha Lower Beles scheme: 85,000 ha Average annual demand: 1,554 Mm^3
Irrigation in the Dinder Subbasin	Dinder (transfer from Beles)	Upper Dinder scheme: 10,000 ha/80,000 Average annual demand: 98.2 Mm^3
Extension of the Finchaa irrigation scheme	Finchaa	Extension from the west bank to the east bank using flow regulated by the existing Finchaa Dam. Additional irrigation area: 12,000 ha Average annual demand: 456.6 Mm^3
Karadobi hydropower scheme	Blue Nile main stem	250 m high dam, total storage: 40,220 Mm^3 Hydropower capacity: 1,600 MW
Mendaya hydropower scheme	Blue Nile main stem	164 m high dam, total storage: 15,900 Mm^3 Hydropower capacity: 1,620 MW
Border hydropower scheme	Blue Nile main stem	90 m high dam, total storage: 11,100 Mm^3 Hydropower capacity: 1,400 MW
Mabil hydropower scheme	Blue Nile main stem	170 m high dam, total storage: 17,200 Mm^3 Hydropower capacity: 1,200 MW
Irrigation in the Guder Subbasin	Guder	Guder diversion: 4,100 ha Guder: 4,896 ha Average annual demand: 54.4 Mm^3
Nekemte	Anger	Nekemte scheme: 11,220 ha Average annual demand: 71.5 Mm^3
Didessa Irrigation	Didessa	Didessa irrigation scheme: 54,058 ha Average annual demand: 769.4 Mm^3
Lower Didessa hydropower	Didessa	110 m high dam, total storage: 5,510 Mm^3 Hydropower capacity: 190 MW
Dabus Irrigation and hydropower	Dabus	Dabus irrigation scheme: 9,661 ha Average annual demand: 69.4 Mm^3 Hydropower capacity: 152 MW
Danguar hydropower scheme	Beles	120 m high dam, total storage: 4,640 Mm^3 Hydropower capacity: 33 MW
Lower Dabus hydropower	Dabus	50 m high dam, total storage: 1,290 Mm^3 Hydropower capacity: 164 MW

Small and Micro Reservoirs

Current

There is limited information on small and micro reservoirs in the Abay River Basin. This may be because micro dams are often initiated by local communities, and so are not embedded in government or international donor programs. Small and micro-dams have been promoted for irrigation, livestock and domestic supply in Ethiopia, but the extent of use is not clear (Eguavoen 2009).

It appears that small dams are not widely used for irrigation in the Abay Basin. Awulachew et al. (2007) list 293 small-scale irrigation projects in the Amhara state with a total area of 5,718 ha. Of these, only 10 projects with a total area of 325 ha use dams as a source of water. None of the 17 listed medium irrigation projects listed draw water from dams; all draw directly from rivers. Gebregziabher (2010) lists a total of 34 dams in an inventory of 1,688 instances of AWM technologies in Amhara. He found a higher incidence of micro-dams for irrigation in the Tigray region, but only in cooler areas, and suggested that high evaporation losses make small and micro-dams unattractive in the more arid regions.

Eguavoen (2009) reports that micro-dams have "indisputable benefits for agricultural production" but may result in significant increase in malaria, schistosomiasis and other water-related diseases. A study in the Tigray state (outside the Abay Basin) reported benefits in terms of food security and increased production, but with problems including salinity, sedimentation and degradation of water quality as well as increased incidence of malaria in areas below 2000 masl (Behailu et al. 2004).

Planned

Micro-dam development is attractive to the regional governments as a way of increasing agricultural productivity, broadening income-generating opportunities and for domestic supply with small investments, using local skills, resources and labor (Eguavoen 2009). The national irrigation development strategy aims to expand small-scale irrigation schemes (Ethiopia National Investment Brief 2008). Ninety sites (total area of 45,856 ha) suitable for small-scale irrigation development have been identified in the Abay Basin (Awulachew et al. 2007). Small and micro-dams are a potential water supply for at least some of these schemes, as there are many sites in the highlands which could be developed for micro-dams.

Ponds and Tanks (Rainwater Harvesting)

Current

The construction of ponds has a long tradition in Ethiopia, and runoff ponds and tanks have been widely promoted by regional government programs. In 2002, about 70,000 ponds and underground tanks were constructed in Amhara and Tigray states (Rämi 2003). The most common type are excavated ponds, which may be lined with clay (cheap, but requires good workmanship), plastic or concrete (both relatively expensive). Despite their apparent simplicity, a number of problems have been reported and outcomes are mixed. AMU (2009) estimates that around 4,000 rainwater harvesting ponds were constructed in the Amhara region of the Abay River Basin between 2003 and 2008, but reports that according to the regional water bureau, most have failed: 50% of cement ponds and almost 80% of plastic lined and earthen ponds were nonfunctional. Poor site selection and design, technical problems and lack of materials for construction, large labor requirements, failure of lining materials leading to seepage, and lack of commitment by communities for completion and maintenance have all been cited as problems (Eguavoen 2009). However, despite these problems demand for plastic geomembranes is increasing, with widespread use of plastic-covered rainwater harvesting ponds both for irrigation and other domestic uses in some villages in the Abay (AMU 2009).

In some regions, *birkas* (underground cisterns constructed with cement or other materials) are the predominant traditional sources of water for humans and livestock, and they have been used for more than 100 years. For example, over 7,000 birkas have been constructed in the Harshim Woreda of Oromia (outside the Abay Basin) (Ayele and Bekele 2010). However, results in other areas using underground tanks have been mixed. Eguavoen (2009) reports on trials of low-cost underground tanks in the Amhara region, comparing four technologies to store $60m^3$ of water each. Hemispherical concrete tanks were most common, but there was a high failure rate due to diverse soil and water conditions and lack of the required masonry skills. In contrast, CARE reported that small water harvesting catchments and cisterns for domestic use were well received and eagerly adopted, with only minor technical problems. They provide a low-cost alternative to boreholes, and can be filled by water tankers in case of rainfall failure (Haile and Merga 2002).

Planned

Construction of small-scale ponds and tanks has been promoted by federal and regional governments as well as NGOs. Much of the money allocated for food security programs has been invested by the regions in the implementation of water harvesting programs, based on the construction of household ponds and cisterns planned and implemented by the Ministry of Agriculture and Rural Development (MoARD) (Ayele and Bekele 2010). The National Irrigation Strategy gives emphasis to water harvesting methods and FAO has proposed investment of $1,500 million over 5 years under NEPAD-CAADP entitled “Water harvesting and small-scale irrigation” (Ethiopia National Investment Brief 2008). However, it is not clear to what extent this has been implemented.

Groundwater

Current

Across Ethiopia, over 75% of rural communities use groundwater for drinking, and the water supply for most large towns comes from shallow or deep boreholes. In the Abay Basin, naturally occurring springs, mainly from the basalt aquifers and often developed and capped to enhance and ensure supply, are common in the highlands and escarpments (Figure 6a). The settlement pattern of rural communities in the highlands is strongly controlled by their distribution. However, the storage capacity of perched aquifers that feed highland springs is often not sufficient to ensure a continuous flow and many dry up during the dry season.

Over 70,000 hand-dug wells were constructed in the Amhara region of the Abay Basin between 2003 and 2008, to access shallow unconfined aquifers (Figure 6b). Such wells are usually 1.5-2.5 m in diameter, and up to 15 m deep (usually less than 5 m). In the highlands, hand-dug wells are restricted to areas with shallow water tables (wetlands, riverbeds and valley bottoms), but they provide water supply and even irrigation in some locations. Generally, the hydraulic conductivity and yield of shallow wells increase from the highlands to the lowlands (Ayenew 2009).

Shallow boreholes (less than 60 m) have been drilled in many parts of the country over the last 30 years, and are currently the most important source of water for the majority of the rural community (Ayenew 2009). Typically, a borehole serves around 350 people. Shallow boreholes are lined with either steel or plastic piping. Water is usually lifted by hand pumps which on average can deliver a maximum of 5-10 m^3d^{-1} (Calow and McDonald 2009). In the Abay Basin, shallow boreholes are mainly drilled in the Quaternary sediments in the lowlands, and in basement complex rocks and fractured basalts in the highlands (Figure 6c). Drilling productive and sustainable boreholes in a complex hydrogeological context is technically difficult, and there are problems related to the use of poor construction materials and pumps, substandard drilling machinery, lack of trained manpower to maintain pumps and high cost of drilling (Hailemichael 2004). With competition between private contractors, the cost of drilling has decreased to around 900 birr m^{-1} (ca. $70) but the quality has also declined and many wells drilled by NGOs stop functioning soon after construction (Ayenew 2009).

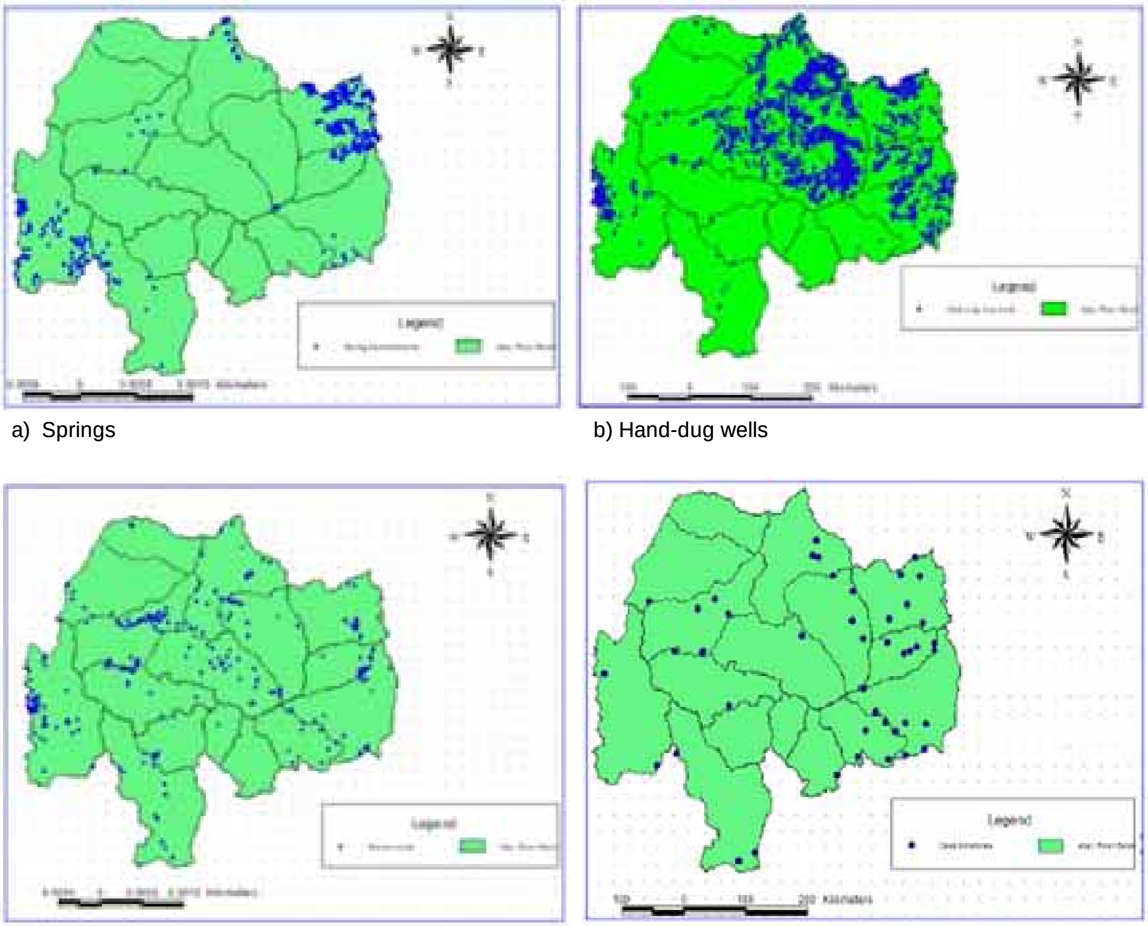
Deep boreholes (>60 m) have been drilled in many urban centers to provide water for both drinking and industrial purposes (Figure 6d). Over 70% of the large towns and most industries (i.e., brewery, food processing, textiles, leather) depend on deep to intermediate boreholes fitted with submersible pumps (Ayenew 2009). Deep boreholes are not common in rural areas. The average depth of deep wells is around 150 m, and the cost of deep drilling is around 1,200-1,300 birr m^{-1} (ca. $100). Properly constructed deep wells have been serving for more than 20 years without any significant problem, but there is often a lack of properly trained people to maintain pumps, even in large towns.

In general, irrigation from groundwater in the basin is very limited. Some small-scale irrigation of vegetables and high-value crops in the highlands utilizes water from high-discharge springs, and there is limited use of shallow and hand-dug wells for irrigation in some areas. The use of irrigation to grow forage is almost nonexistent in the basin. With the exception of some lowland areas, the use of constructed watering points for livestock is limited. Rivers, streams and seasonal ponds are the major source of water for livestock.

To prevent the overexploitation of groundwater resources, some regulation was established in the Amhara region (i.e., specified minimum distances between wells) (Rämi 2003). Projects to enhance recharge of groundwater using ditches, trenches, unsealed ponds and semicircles are rare, although GTZ considered this to be a promising technology (Rämi 2003).

Planned

The potential for groundwater irrigation in the Abay Basin is considerable. The National Irrigation Development Strategy will consider the use of groundwater resources (Ethiopia National Investment Brief 2008). In the highlands, the best areas for groundwater exploitation are the plains surrounding Lake Tana, the central plateau and the river valleys of the major tributaries of the Abay River. The highland volcanic aquifers are highly productive, but the complex stratigraphy means that delineating the lateral extent of aquifers is difficult. Many places in the lowlands could be irrigated using shallow groundwater recharged from the adjacent highlands. For example, lowland areas between Metema and Pawi where highly fractured permeable volcanics covered with Quaternary sediments provide potentially high-yielding aquifers.



a) Springs

b) Hand-dug wells

c) Shallow boreholes

d) Deep boreholes

FIGURE 6. Location of groundwater access (*Source:* AMU 2009).

Groundwater will continue to be the mainstay for rural water supply. UNICEF assessed the requirements for drinking water to meet the Millennium Development Goals (MDG) for different regions of the Abay Basin, and concluded that around 10,000 deep wells and 30,000 shallow wells would be needed in the three states (Table 3).

TABLE 3. UNICEF future water development scenario for rural population (*Source:* Hailemichael 2004).

	Population (million)	Hand-dug wells (%)	Springs (%)	Shallow wells		Deep wells	
				(%)	(Number*)	(%)	(Number)
Amhara	9.02	18	20	46	11,859	16	2,887
Oromia	0.33	19	23	40	20,483	18	6,452
Beninshangul	17.92	15	5	69	648	11	72

*Each shallow well is assumed to serve a population of 350.

Soil Moisture Storage

Current

Both traditional rainwater harvesting techniques (such as runoff farming) and in-situ water harvesting techniques (such as micro-basins) are used in Ethiopia. Government SWC programs were started during the 1970s and 1980s, promoting the use of *fanya juu* (earthen bund/terrace structures), stone bunds, grass strips, diversion ditches and check dams. These were initiated primarily to address concerns of soil erosion and not specifically soil moisture. Over 2 Mha of cultivated land within the Abay Basin are subject to “unsustainable” erosion with soil loss over 12.5 $tha^{-1}y^{-1}$ as a consequence of deforestation, expansion of agriculture into increasingly steeper areas and poor land management practices (Awulachew et al. 2008). In addition to in-field impacts such as soil loss and reduced soil fertility, deposition of eroded sediments downstream causes siltation of dams, ponds and canals.

In the wake of the 1985 famine, the Government of Ethiopia launched an ambitious program of SWC supported by donors and NGOs and backed up by the largest food-for-work (FFW) program in Africa (Hoben 1996). Despite this, uptake of SWC techniques has been limited for a variety of reasons including: missing the priorities of the farmers; farmers perceiving the work as too hard and the technologies too difficult; complaints about lost land due to SWC; difficulty of ploughing with oxen; insecure land tenure; and cessation of donor-funding (Bewket 2007). Results from study sites within the Abay Basin indicate that although soil loss and runoff were generally reduced, biomass production on SWC sites was often lower than on control sites, due mainly to 10-20% of land taken up by the structure (AMU 2009). Half the number of farmers indicated that their participation was enforced by agricultural extension offices, rather than self-motivated, and the suggested technologies were not sufficiently adapted to local conditions (Bewket and Sterk 2002; Amsalu and de Graaff 2007).

Planned

The FFW program of the Government of Ethiopia is being continued through the Public Works Component of the Productive Safety Net Program, with an annual operating budget of nearly $500 million (Gilligan et al. 2008). The work carried out within this program is labor-intensive and is intended to build community assets. Much of it comprises SWC measures.

The Community-based Integrated Natural Resources Management Project, with total co-funding of $25 million by IFAD and GEF will support implementation of about 650 watershed management plans in the Lake Tana watershed to restore the productivity of a large area of degraded land.[4] The Koga irrigation and watershed management project (under AfDB) includes a component of watershed management, including soil conservation, integration of livestock and forestry improvement to complement smallholder irrigation development from the Koga Reservoir. This project will act as a model for other areas, including Ribb and Gumera watersheds, also located in the Lake Tana Basin. Ethiopia’s national hydropower development strategy aims to implement appropriate watershed management measures to ensure longer life of hydropower dams by minimizing siltation of waterways and reservoirs (Ethiopia National Investment Brief 2008). However, in all cases the primary motivation remains reduced soil erosion rather than enhanced water infiltration.

[4] http://operations.ifad.org/web/ifad/operations/country/home/tags/ethiopia

Wetlands

Current

The wetlands of Ethiopia represent a significant environment in the country, estimated to cover around 1.5% of total land area (1.43% within the Abay Basin). Wetlands are much more common in the Amhara region (2.74% of area) than in Oromia (1.11%) or Benishangul-Gumuz (0.45%) (AMU 2009). Abebe and Geheb (2003) list 73 significant wetland sites nationally. Of these, seven lie within the Abay Basin (Aloba Lake, Ashenge Lake, Chomen Lake, Fogera Swamps, Tana Lake, Wonchi Lake, Zangana Lake), and there are many other small wetlands within the basin.

Wetlands are used extensively for a range of purposes including domestic water supply and agriculture (Wood 2001). Because of the importance of livestock in the basin many are used for grazing. In many places grazing strategies follow distinct seasonal and spatial patterns with grazing pressure focused on wetlands during the dry season and in uplands during the rainy season when the wetlands are too wet (Mwendera et al. 1997). Rice farming in swamp areas is practiced south of Gonder in Amhara, on the Fogera floodplain wetlands (around Lake Tana) and also in the Dabus wetland (Gebregziabher 2010).

Planned

Currently, Ethiopia is not a signatory to the Ramsar convention and there is no national wetland strategy. Wetland issues are mentioned in both the national Conservation Strategy and Environmental Policy but are not addressed in a comprehensive manner. Some regional conservation strategies deal specifically with wetlands (e.g., Gambella) but others do not (Mesfin 2003). Consequently, protection of wetlands as well as their development for agriculture are haphazard with little planning at either national or regional level. There are no statistics on the extent of wetland utilization, and there is no readily accessible information on plans for wetland use/conservation in the future. Where wetlands are used for agriculture it is a consequence of local community action. In places, local bylaws have been established to manage wetland use and protect what is seen by many communities as a valuable resource. However, increasing population and the resultant pressure on agricultural land are increasing pressure on wetlands resulting in degradation in places.

VOLTA BASIN IN GHANA

The Volta River Basin in West Africa covers an area of 400,000 km^2 in six West African countries (42% in Ghana, 43% in Burkina Faso, and 15% in the other four countries: Togo, Benin, Cote d'Ivoire and Mali). The area within Ghana is almost 168,000 km^2, comprising 70% of Ghana's total area, a population of around 8.6 million (a third of the total population) and 70% of total water resources. The Akosombo Dam was constructed on the Lower Volta in 1965 about 100 km from the sea to form Lake Volta, one of the largest man-made reservoirs in the world, covering 8,500 km^2 (4% of Ghana's land area). A detailed description of the basin characteristics can be found in Barry et al. 2005.

Hydrology and Climate

The Volta River system consists of the Black Volta in the west, the White and Red Volta (each flowing from Burkina Faso), and the Oti River in the east (draining the highlands of Togo and Benin). These join in Ghana to form the Lower Volta before flowing into the Gulf of Guinea (Figure 7). The mean annual flow in the Volta River system is approximately 35.6 Bm^3 but, there is considerable interannual variation (11.3 Bm^3 to 66.6 Bm^3 before construction of the Akosombo Dam). Flows are seasonal, following the rainfall patterns except in the Lower Volta where regulation by the Akosombo Dam has virtually removed any seasonal variation.

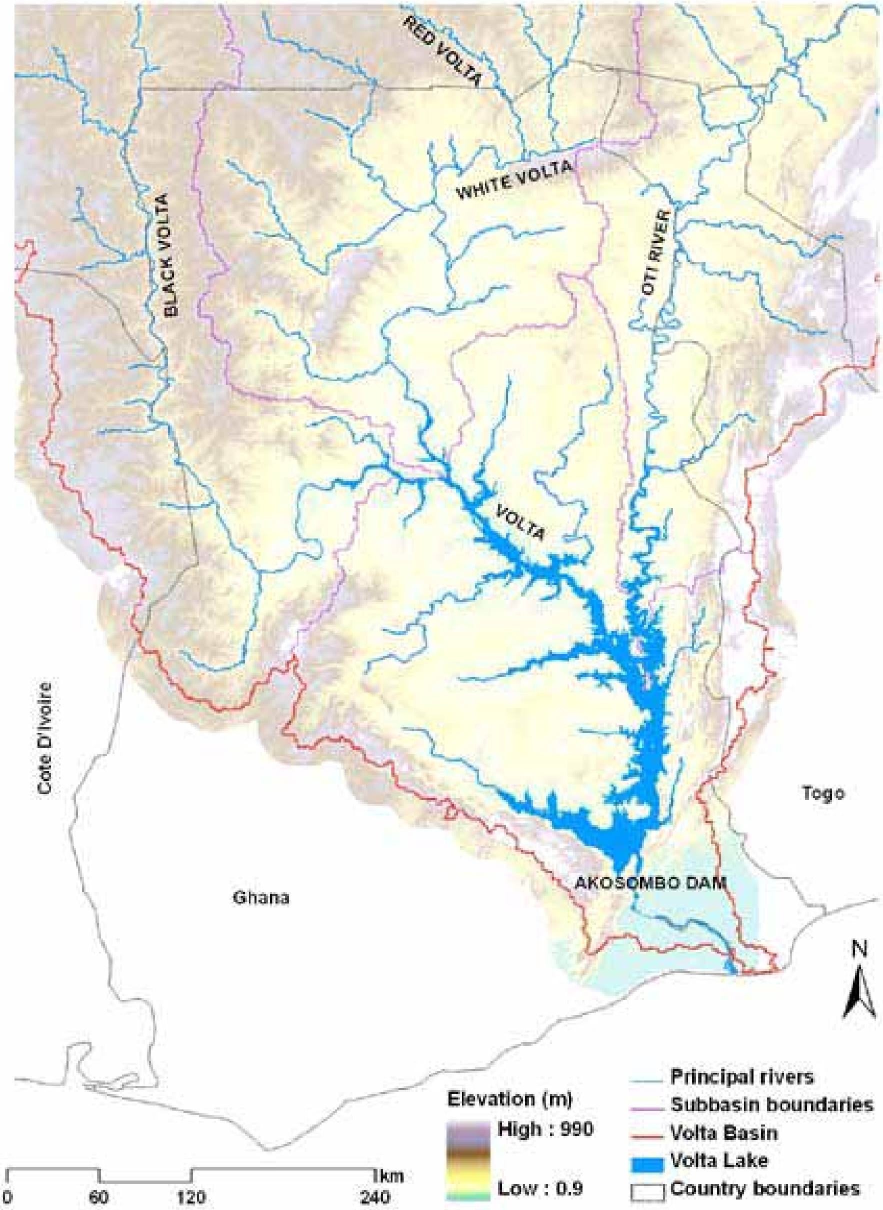


FIGURE 7. Map of the Volta Basin.

The average annual rainfall varies from approximately 1,600 mm in the southeastern section of the basin in Ghana, to about 800 mm in the northern part of Ghana (with an average across the basin of 1,320 mm). The annual mean temperature in the basin varies from about 27 to 30 °C. Potential evapotranspiration is generally significantly higher than rainfall (Figure 8) increasing towards the north (while rainfall decreases), and ranges from 1,450 mm in the Black Volta Subbasin to 1,968 mm in the White Volta Subbasin. The south of the Ghana has bimodal rainfall, with wet seasons in June/July and October. In northern and central Ghana, there is a single wet season, with around 80% of rain falling between June and October. In the north, the dry season extends for up to 7 months with virtually no rainfall.

(a) (b)

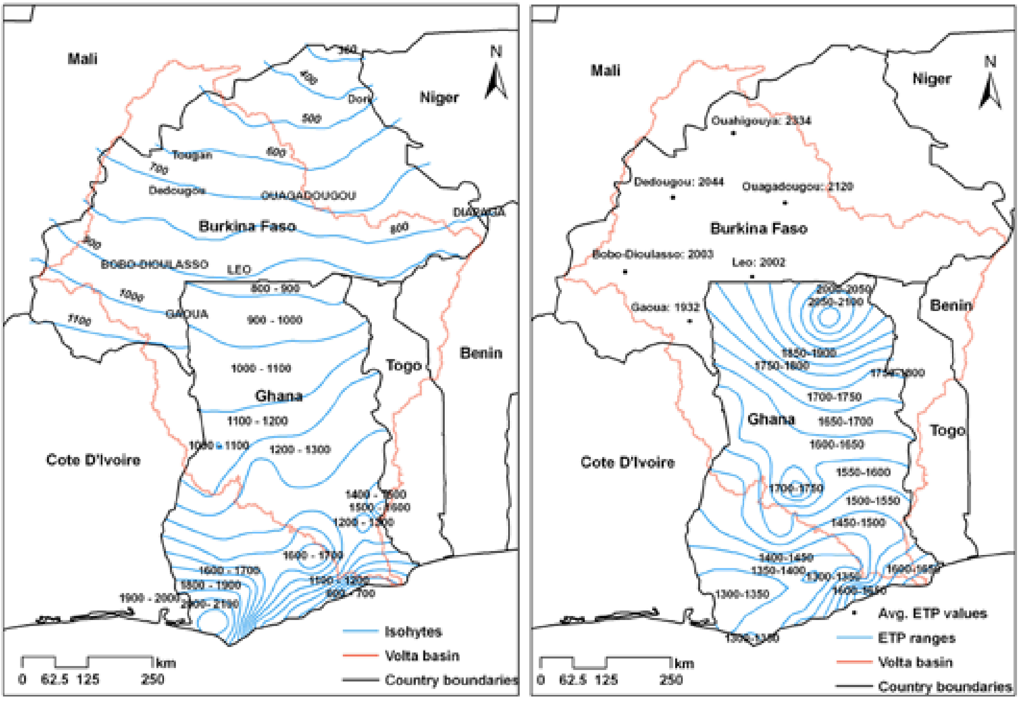


FIGURE 8. (a) Rainfall; and (b) Potential evaporation in Ghana (*Source*: Barry et al. 2005).

A rise of 1 °C in average annual temperature was recorded over the period 1945-1990, and mean annual rainfall in northern Ghana decreased by up to 11% in the period 1971-1991, compared to the preceding 20 years (Gyau-Boakye and Tumbulto 2006). Projections for future climate change vary between studies. While there is general agreement that temperatures will increase, there is no consensus on whether rainfall in West Africa will increase or decrease (Christensen et al. 2007). A regional analysis on the impact of climate change on the Volta Basin to 2039 predicted an increase not only in the duration of the dry season and the unpredictability of the onset of the rainy season but also in the amount and intensity of rainfall in the wet season (Kunstmann and Jung 2005). Another study using different GCM-based scenarios predicted more extreme impacts, with decline of river flows in the Volta of 9-23% by 2020 and 24-51% by 2050 (CSIR-WRI 2000 reported in Laube et al. 2008). Both studies agree that water availability will be further reduced by higher temperatures and increased evapotranspiration. A third study concluded that inflows to Lake Volta are highly sensitive to interannual rainfall. Changes in climate of similar magnitude to variability observed in the past would have critical impacts on Lake Volta and hydropower generation (de Condappa et al. 2009).

Groundwater

Ghana has substantial groundwater resources: total renewable groundwater resources are estimated to be 26.3 Bm^3 (FAO 2005b). Reviews of groundwater resources and use in Ghana are found in Kortatsi 1994 and Agyekum and Dapaah-Siakwan 2008. The Volta Basin is underlain by consolidated Paleozoic sedimentary sequences, referred to as the Voltaian Formation, and Precambrian basement complex (igneous and metamorphic rocks), mainly in the north (Kortatsi 1994; Barry et al. 2005). Both are essentially impermeable, so that the occurrence of groundwater is associated with the development of secondary porosity through jointing, shearing and fracturing, and with overlying deeply weathered regolith. The regolith aquifers usually occur at the base of the thick weathered layer, which ranges from an average of 60 m in the wet forested area in the southwest to 10 m in the semiarid zone in the northeast. The fractured zone aquifers occur at some depth beneath the weathered zone, but are also usually quite shallow (<120 m). Both types of aquifer are normally discontinuous and limited in area. Due to the sandy clay nature of the weathered overburden, the groundwater occurs mostly under semi-confined conditions (Kortatsi 1994).

Recharge to aquifer systems in Ghana is mainly by direct infiltration of precipitation through fracture and fault zones along the highland fronts, through the sandy portions of the weathered zone and as seepage from ephemeral streams during the rainy season. Recharge rates vary considerably between wet and dry years but are estimated at around 8-17% of the mean annual rainfall (Kankam-Yeboah and Opoku-Duah 2004). In general, groundwater extractions are too small to impact regional water balances (Lutz et al. 2007). However, falling groundwater levels have been observed in the Upper Regions where there have been extensive drilling programs to provide potable water to rural communities (FAO 2005b). Groundwater quality is generally good, but many hand-dug wells contain high levels of nitrate and abundant coliform due to inadequate protection of the well sites from surface runoff and animals (Kortatsi 1994).

Land Use

The basin has a low relief with altitudes varying up to 920 m with a mean of 257 m. Within Ghana, most of the basin is savannah, used for extensive grazing, and a mixture of stationary farming and shifting cultivation. A band of semi-deciduous forest exists in the southwest of the basin (in the bimodal rainfall zone). This is an important area for permanent cultivation of food crops and cocoa, as well as timber. The transitional zone between the forest in the south and the savanah zone (about 50 km wide) is an important agricultural area, with permanent mechanized cultivation of food crops being common.

Importance of Water Storage

Statistically, Ghana has abundant water resources. Per capita renewable water resource is estimated at over 2,400 m^3y^{-1} and per capita storage at 6,500m^3. However, these values do not give an accurate picture of access to water. Rainfall is variable, both seasonally and from year to year. Many watercourses, apart from major rivers, are ephemeral. The very low level of total withdrawals for all purposes (equivalent to per capita abstraction of less than 140 ld^{-1}) including domestic withdrawals (around 30 ld^{-1}) reflects the difficulty in accessing water. High per capita storage is entirely due to the huge volume of Lake Volta, but this is directly accessible only to a small proportion of Ghana's population. Excluding Lake Volta, per capita storage is just 12 m^3.

The main consumptive water uses in Ghana are for domestic (24%), industrial (10%) and irrigation (66%) purposes. Current annual water use for hydroelectricity generation (at the Akosombo and Kpong dams) averages 31.57 Bm^3 (de Condappa et al. 2009). Although this use is nonconsumptive, it occurs close to the end of the basin, and there is little opportunity for reuse. Van der Giesen et al. (2001) argue that because Ghana has sought economic development through its industrial and mining sectors, water is used mainly to generate cheap hydropower to fuel industrial growth, and that power use in industry and urban areas is sustained at the cost of water use in other sectors.

As in Ethiopia, agriculture contributes approximately 40% of the GDP (FAO 2005b). However, economic growth is less dependent on agriculture and so less dependent on rainfall. Since the mid-1990s, economic liberalization and increased production in commercial, drought- resistant crops such as cocoa have largely decoupled GDP growth from rainfall (Namara pers. comm.). The importance of the mining, industrial and service sectors in growth since the mid-1980s has also contributed to this phenomenon. The main significance of storage, then, is to ensure domestic supply, food production in the dry northern regions, and provide hydroelectricity for industry (mainly aluminium smelting).

Securing Food Production and Livelihoods

Rain-fed agriculture by smallholders dominates food production in Ghana, accounting for 80% of total agricultural production. The dry season in most of the country is long, with up to 7 months with no significant rain. Complete crop failures due to drought occur in most northern areas in one in 3–5 years (FAO 2005b). Annual variation in cereal production from 1992 to 2001 was only 5.8% compared to 18% in Ethiopia (Earthtrends 2009) but nationally, around 9% of the population are undernourished, and levels of hunger are classed as serious (von Grebmer et al. 2008). Poverty rates amongst food crop farmers are significantly higher than in the population as a whole. Secure water supplies for domestic and livestock use, and for home gardens, during the dry season are a critical component of food security. Small-scale storage (reservoirs, ponds and tanks), rainwater harvesting and groundwater all play an important role in ensuring water supply at the household level.

Irrigation

In view of the seasonal variability and occurrence of drought in the Volta Basin, the development of storage for irrigation is generally considered an essential component of food security and economic development. The Ghana Poverty Reduction Strategy 2003-2005 (GPRS) lists irrigation as a priority. However, irrigation currently contributes less than 3% of Ghana’s food production and returns from investment in irrigation have been mixed. Access to irrigation can provide significant increases in yield. For example, rice yields under irrigation average 4.6 tonnes ha^{-1} compared to only 1.0–1.5 tonnes ha^{-1} under rain-fed conditions (FAO 2005b) but this does not always translate into increased incomes. The Agricultural Water Management project in Ghana reports a large range in net revenue in irrigation systems (IWMI unpublished data). Farmers growing high-value crops such as vegetables with gravity-fed irrigation have higher incomes, but those growing rice with pumping schemes tend to be worse-off due to high pumping and maintenance costs (FAO 2005b). In addition, water-related diseases such as elephantitis have been linked to irrigation projects (Hunter 1992) and irrigation is reported to have significantly increased the prevalence of malaria in some areas (Klinkenberg et al. 2005).

The total area of formal irrigation in the Ghanaian part of the Volta Basin is only about 6,000 ha located within 12 irrigation schemes (Table 4). There is little information on informal irrigation in the basin but peri-urban irrigation (using wastewater) around cities like Kumasi is quite extensive (Mensah et al. 2001). Potential irrigable area in Ghana is estimated at 1.9 Mha, or 19% of the cultivable area (Kankam-Yeboah and Opoku-Duah 2004). Of this, about 0.5 Mha have been tentatively estimated within the Volta Basin. Valley bottoms and flood plains add another 1.0 Mha that could be cultivated mostly to rice by employing water management technologies (Ghana National Investment Brief 2008).

Hydropower

Hydropower from the Akosombo (1012 MW) and Kpong (160 MW) dams provides the majority of Ghana's total electricity requirements, though the proportion fluctuates from year to year (e.g., from 92% in 2000 to 67% in 2006 to 53% in 2007) depending on water conditions. Despite this, hydropower contributes only a small proportion (around 3.4% in 2007) of total primary energy supply, with the majority (61%) from renewables (mainly fuelwood) and 31% from oil (IEA 2009). Only 40% of the total population has access to electricity. The electricity industry contributes 2.8% of real GDP (including sales to Togo and Benin) and 10.65% of industrial GDP (Asante 2009). Of the power generated from Akosombo, around 20% is supplied to the national grid, with 80% supplied to the Volta Aluminium Company for use in the Valco aluminium smelter. Because of the relatively flat terrain potential hydropower development in Ghana (10,600 $GWhy^{-1}$) is a lot less than in Ethiopia. However, additional large and small hydropower stations (totaling more than 525 MW) are planned for the Volta Basin.

Domestic and Industrial Water Supply

Water supply for Greater Accra is drawn from the Volta River at Kpong, downstream of Lake Volta. Outside Accra, urban water delivery systems are sourced mainly from smaller rivers (Asante 2009) with around 5% from groundwater (FAO 2005b). The Ghana Water Company Limited (GWCL) owns and operates 33 run-of-river systems for water supply, mostly weir systems. The company also abstracts water from mechanized boreholes and from some of the formal irrigation dams such as Vea in the Upper East Region (UER), for potable water.

In rural areas, groundwater is the most common source for domestic water supplies, providing between 50 and 78% of supplies in different regions (CSIR-WRI 2009). Other traditional sources of supply are streams, which are often ephemeral and unreliable, and small ponds and shallow wells, both of which are easily polluted. These are gradually being replaced by groundwater boreholes by the Community Water and Sanitation Agency, the government agency responsible for rural water supply. In 2008, nationally 74% of households had access to an improved water source, but this was lower (64%) in rural areas (WHO-UNICEF 2010).

INVENTORY OF CURRENT STORAGE IN THE VOLTA BASIN IN GHANA

Large and Medium Reservoirs

Current

There are 10 formal large and medium dams in the Volta Basin in Ghana, from a total of 22 nationally (Figure 9). Excluding Lake Volta, the total storage is 531.5 Mm^3. The Akosombo Reservoir has a gross storage capacity of 148 Bm^3 with an active capacity of 78 Bm^3. The total annual flow into the lake is around 36 Bm^3. Evaporation from the lake is estimated at 10.2 Bm^3 but direct rainfall on the lake is 7.9 Bm^3 so that only about 7.5% of the annual inflow is lost to evaporation (van de Giesen et al. 2001). The Kpong Reservoir, 40 km downstream of Akosombo, has a total storage of only 2.5 Mm^3 and is operated in tandem with Akosombo as a run-of-river system. Low water levels in Lake Volta in 1997-98 and 2007-08 forced cuts in power generation from the Akosombo Dam. Lake Volta supplies some small areas of irrigation on the Accra Plains. The Kpong Irrigation Project irrigates 2,200 ha and serves over 3,000 rice farmers, extracting about 33 Mm^3 of water from the Kpong Reservoir, annually.

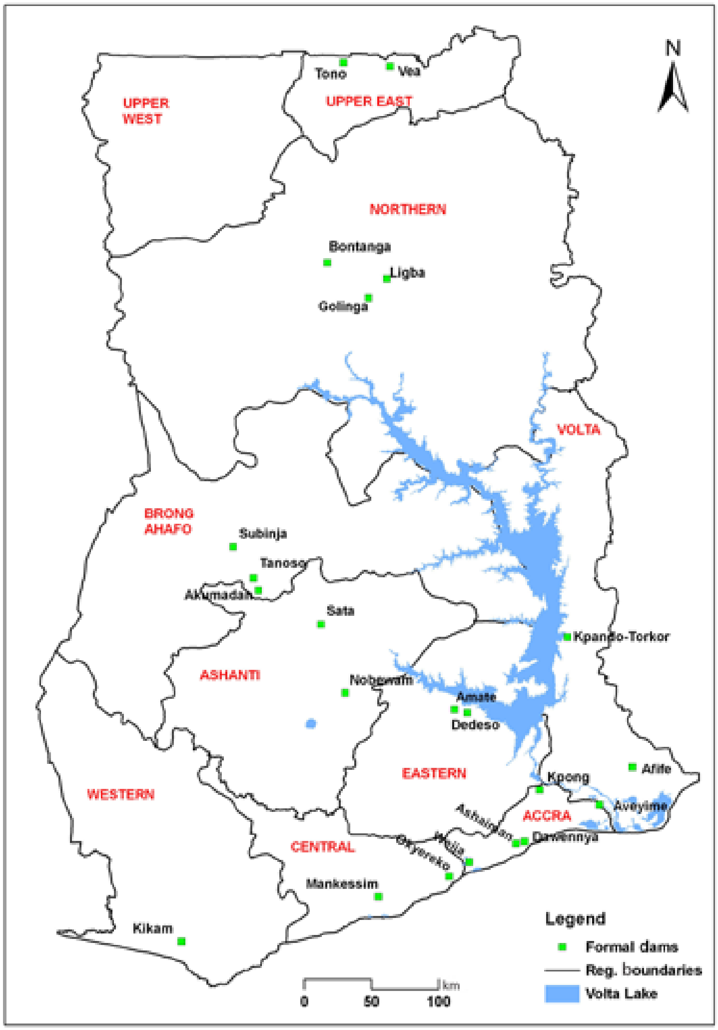


FIGURE 9. Large dams in Ghana (*Source*: Asante 2009).

The remaining reservoirs were built specifically to provide water for irrigation. The Ghana Irrigation Development Authority (GIDA) operates 21 irrigation systems in the country, of which 11 lie within the Volta Basin (Table 4). There is no relationship between the size of the reservoir and area irrigated. Design capacity of irrigated areas from large reservoirs in the Volta Basin (excluding Lake Volta) is 9,015 ha, but many irrigation areas have not been fully developed. Schemes are often poorly maintained and in many years, only a proportion of equipped area is actually cultivated. For example, Amate has an irrigable area of 202 ha, but none is currently cropped. Similarly at Dedesor, of 60 ha only 20-25 ha are cropped, and Aveyime, Sata and Subinja schemes are not currently operating (Asante 2009).

TABLE 4. Large dams and irrigation schemes in the Volta Basin of Ghana (Asante 2009).

Region	Project	Storage capacity Mm^3	Type of system	Irrigation (ha) Potential	Irrigation (ha) Developed
	Akosombo	148,000	Concrete dam		
Volta	Aveyime		Pump system	150	63
	Kpando-Torko	-	Pump system Volta River	355	40
Northern	Bontanga	25	Earth dam (gravity)	450	450
	Golinga	9.5	Earth dam (gravity)	100	40
	Libga	5.9	Earth dam (gravity)	40	20
Upper East	Tono	92.6	Earth dam (gravity)	3,860	2,430
	Vea	16	Earth dam (gravity)	1,200	850
Brong Ahafo	Subinja	135	Weir (pump/sprinkler)	120	60
	Tanoso	125	Weir (pump/sprinkler)	115	64
Ashanti	Akumadan		Concrete dam (pump/ sprinkler)	65	65
	Sata		Weir (gravity)	55	34
Eastern	Amate	120	Weir (pump/sprinkler)	200	101
	Dedesor	Lake Volta	Weir (pump/sprinkler)	400	25
Greater Accra	Kpong	2.5	Dam (gravity)	3,200	2,200

Planned

The Bui Dam, currently under construction on the Black Volta, will impound a reservoir with an area of 440 km^2, total storage of 12.35 Bm^3 and active storage of 6 Bm^3. The project is designed for multipurposes, with 400 MW of generating capacity as well as irrigation, fisheries and tourism potential. It will improve security of electricity supply in central and northern Ghana and has potential for export of power to Burkina Faso. The estimated irrigation potential of the project is about 30,000 ha (Asante 2009).

Eight other proposed hydropower projects have been identified in the Volta Basin in Ghana (Table 5), including the Juale project on the Oti River and the Pwalugu project on the White Volta, planned to be operational by 2012 and 2020, respectively (Ghana National Investment Brief 2008). The total proposed additional live storage (including Bui) amounts to 28.6 Bm^3.

Investments of around $40 million are planned to rehabilitate existing large irrigation schemes, including the Tono and Vea irrigation schemes in the UER. A feasibility study is currently being conducted of the 160,000 ha Accra Plains Irrigation Project downstream of the Kpong Hydropower

Dam. If adopted, it will be implemented between 2012 and 2017 with funding from Libya. In addition to the development of irrigation downstream of the Bui Dam, GIDA also plans to undertake feasibility studies for six large irrigation projects totaling 13,680 ha (Table 6). Two of these would involve storage dams. A feasibility study for a large irrigation scheme associated with the hydropower development at Pwalugu (134,000 ha) is also planned.

TABLE 5. Proposed hydropower projects in Volta Basin in Ghana.

River basin	Location	Potential (MW)	Live storage volume (Mm^3)	Annual energy generation (GWh)
Black Volta	Koulbi	68	2,950	392
	Ntereso	64	1,370	257
	Lanka	95	-	319
	Bui*	400	5,620	1,000
	Jambito	55	760	180
Total		682	10,700	2,148
White Volta	Pwalugu*	48	3,260	184
	Kulpawn*	36	4,800	166
	Daboya*	43	2,670	194
Oti	Juale	87	7,200	
Total		214	17,930	544

Source: Engineering Services Department, Volta River Authority.
* Sites with pre-feasibility studies already carried out.

TABLE 6. Proposed large irrigation schemes.

Project	Region	Irrigated area (ha)	Dam storage (Mm^3)	Hydro project
Kamba	Upper West	2,429		
Tamne	Upper East	1,500	37.5	
Binaba	Upper East	2,850		
Mpaha	Northern	5,500		
Passam	Northern	1,200	39.5	
Adidome	Volta	202		
Pwalugu	Upper East	134,000	3,260	Pwalugu
Bui	Brong Ahafo	71,000	5,620	Bui
Accra Plains	Greater Accra	160,000	2.5	Kpong

Small and Micro Reservoirs

Current

In the semiarid regions of northern Ghana, large numbers of small reservoirs have been constructed. These are used as multipurpose water sources for irrigated agriculture and gardening, livestock watering and fishing, as well as personal hygiene, domestic uses, income-generation and building (Liebe et al. 2007). Private irrigation schemes drawing on small and micro reservoirs in Ghana are estimated at around 30% of total irrigated area (FAO 2005b). There is limited information on the distribution and significance of these dams in most areas. However, using remote sensing more than 500 small reservoirs have been identified in the UER (Liebe et al. 2005). Almost 70% of the reservoirs were less than 1 ha in area. The rest ranged from 1 to 35 ha. The distribution of reservoirs was found to depend on population density with more reservoirs in the more densely populated areas. The UER is the driest region in the Volta Basin in Ghana and so has the highest demand for such storage systems. Adjoining areas in Burkina Faso, with even lower rainfall, have similarly large numbers of small reservoirs, but they are less common in central and southern Ghana (CSIR-WRI 2009).

Evaporative losses are very high and most small dams dry out progressively during the dry season. The total annual storage of all small reservoirs in the UER is estimated to be 185 Mm^3 with estimated annual evaporation losses of nearly 176 Mm^3 (Liebe 2002). Water is also lost through percolation to groundwater, though this may then be available for use elsewhere. There is some concern that construction of large numbers of small reservoirs may reduce the overall yield from watersheds, and so reduce the flow to Lake Volta. The overall impact of small reservoirs depends on the ratio of reservoirs to watershed area but in the Ghanaian Volta, small reservoirs capture, on average, about 15% of the overall runoff (Liebe et al. 2009).

A study of two small reservoir irrigation schemes in UER found that returns on water and labor are low and it is unlikely that the relatively high capital investments (dam, intakes, lined canals) can be amortized through returns from the irrigation schemes alone (Faulkner et al. 2007). In addition, despite similarities in size and socioeconomic and physical environments, large differences were found in water and land profitability between the two schemes. For future investment, it is important to understand the social and institutional reasons for these differences, and to factor in the low profitability for irrigation. Other uses of the reservoirs, including improved household water supply, fishing, livestock watering, and brick making, may be more important than irrigation.

During 2003-2007, IFAD and the Government of Ghana invested $15.4 million in construction and rehabilitation of small dams for communities in the UER under the Land Conservation and Smallholder Rehabilitation Project (LACOSREP). An additional $10.8 million was targeted for small dams and irrigation systems for communities in the Upper West Region (UWR), under the Upper West Agricultural Development Project (UWADP). When the UWADP project closed in 2004, total additional irrigated area was reported as 154 ha (out of a target of 220 ha) but an evaluation team was able to identify only 23 ha and irrigation infrastructure was incomplete on several projects.[5] Results from LACOSREP were similar,[6] with delays in contracting and construction of dams and irrigation infrastructure.

Planned

Significant investments are underway or proposed under a range of programs, including the Comprehensive Africa Agriculture Development Programme (CAADP), various IFAD and FAO agricultural development programs and NGO water supply programs (Oxfam, WaterAid and others). As a priority, the Draft National Irrigation Policy (GIDA 2006) identifies ongoing rehabilitation of 70 breached small earth dams in UER, UWR and the Northern Region. There are also plans to develop 22,590 ha of small- or micro-scale irrigation and drainage schemes within 5 years in five regions of Ghana (including UER, UWR and the Northern Region).

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[5] http://www.ifad.org/evaluation/public_html/eksyst/doc/prj/region/pa/ghana/gh_uwadep.htm

[6] http://www.ifad.org/evaluation/public_html/eksyst/doc/agreement/pa/ghana_lacos.htm

Under the auspices of the Energy Commission of Ghana 22 potential mini hydro sites with generating capacity of 75 to 1,000 KW have been identified and studied but only seven of these sites are still considered prospective (Sven and Ofosu-Ahenkorah 2002). Most are located at waterfalls and some would require small dams for storage.

Ponds and Tanks (Rainwater Harvesting)

Current

Over 30% of households in northern Ghana collect and store rainwater for domestic purposes as well as for income-generating activities, including food vending, crop processing, watering of livestock and gardening (Barry et al. 2005). The rainwater is typically harvested from roofs, and stored in ferro-cement tanks. A 5,000 liter tank provides an average household with 150 ld^{-1} and more than 130 days' supply of water. Rainwater harvesting for irrigation is not currently widespread in Ghana, except for home (compound) gardens. However, dugouts, which are common in the northern part of the basin, are extensively used for livestock watering and sometimes for irrigation of small (0.4 to 1 ha) vegetable gardens. There are no data on the number of dugouts in the basin.

Planned

From 2006 to 2011, an investment of $36 million is planned to promote agricultural production through rainwater management and improvements to existing community-based irrigation activities under the Afram Agricultural Development Project (Afram Plains). The Food and Agricultural Sector Development Programme (FASDEP II), the Northern Region Poverty-Reduction Programme (funded by IFAD) and Northern Rural Growth Programme (IFAD/ADB) all have components to address rainwater management. The Draft National Irrigation Policy (GIDA 2006) includes provision for development of 100,000 ha of sustainable water harvesting and agricultural water management schemes in southern and northern savannah zones, with the first phase comprising 62,000 ha in the UER and Northern Regions.

Groundwater

Current

Groundwater supplies approximately 56% of rural communities nationally, though the proportion in some regions is higher (e.g., 78% in the UWR) (CSIR-WRI 2009). Over 80% of groundwater extractions are used for drinking and other domestic purposes. The use of groundwater for watering livestock and poultry and for irrigation of crops is limited but increasing (Obuobie and Barry forthcoming).

Groundwater is commonly accessed using shallow boreholes fitted with hand pumps or, in a few cases, mechanized pumps. There were altogether 21,548 boreholes across Ghana in 2008, up from 10,500 in 1994 (Kortatsi 1994). Of these around 19,000 are within the Volta Basin, with over 6,280 in the UER, UWR and Northern Region (CSIR-WRI 2006). The distribution of known boreholes is shown in Figure 10, but not all boreholes in the basin have been mapped.

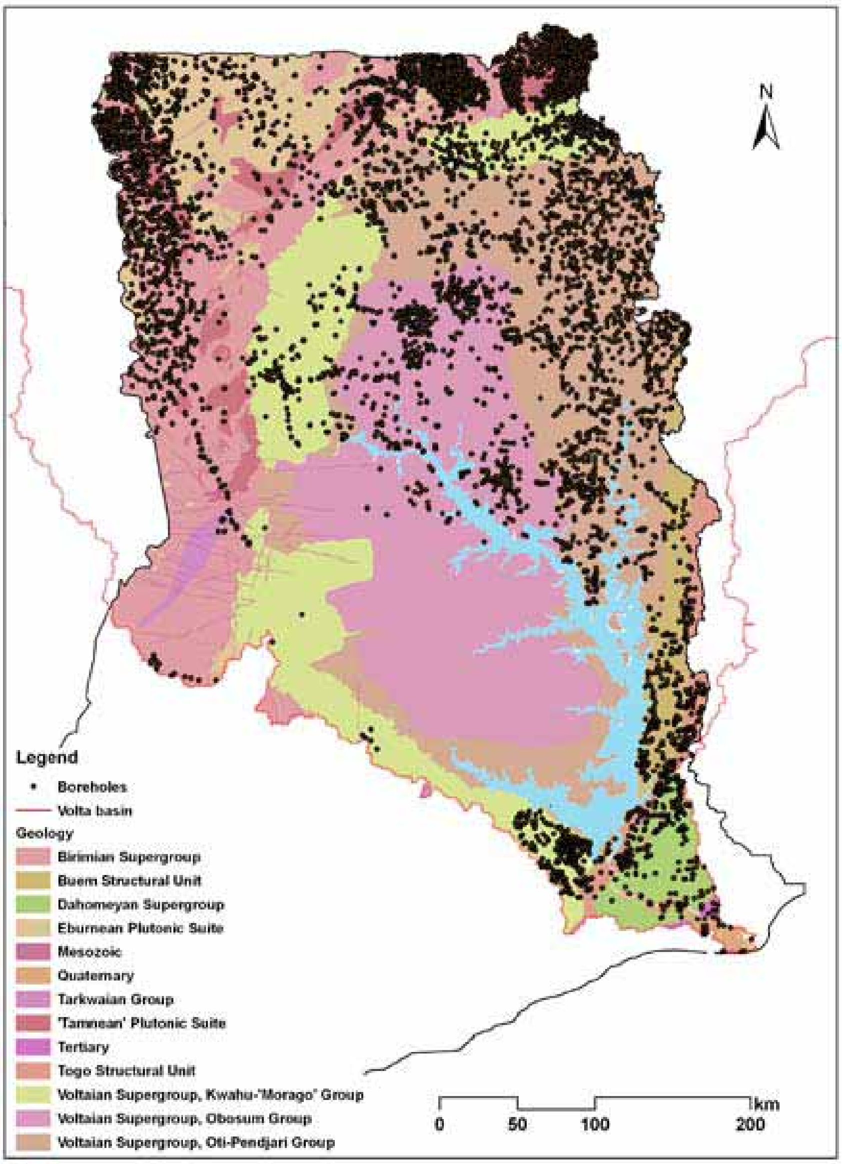

FIGURE 10. Map of known borehole locations in Ghana and the Volta Basin.

Yields from boreholes are variable because of the lithological variation and structural complexities of the rocks, but are generally low, with few boreholes yielding more than 168 m^3d^{-1} and most in the range of 24-72 m^3d^{-1} (Obuobie and Barry forthcoming). Yields of boreholes in the basin have been found to be largely independent of well depth and, in most cases, it has not been found worthwhile to drill below 80 m (CSIR-WRI 2009). A survey of 2,458 boreholes in northeast Ghana reported borehole depths of 28-60 m, and an average yield of 69 m^3d^{-1} with higher yields in the fractured zone aquifers. Under the 'Small Towns Water Supply Project' of the CWSA, very high-yielding boreholes in peri-urban areas are being mechanized for water supply to populations of 2,000 to 20,000 (CSIR-WRI 2006). Mechanized boreholes for several communities, for example in the UER, have yields ranging from 96 to 720 m^3d^{-1} (CSIR-WRI 2006).

Hand-dug wells have been used extensively as a traditional water supply system in many rural and urban communities throughout Ghana. In 1998, there were approximately 60,000 all over the country (Dapaah-Siakwan and Gyau-Boakye 2000). The average depth in the Volta Basin is about 5 m, accessing water from shallow weathered zone aquifers, or shallow alluvial aquifers in ephemeral streambeds. The yield of hand-dug wells varies from 0 (dry well) to 26 m^3d^{-1} with a mean of 6 m^3d^{-1} (Kortatsi 1994). Some perennial springs are found in the forested highland areas of Ghana. The Volta region has 143 inventoried perennial springs (WRRI 1993), but these are often in remote areas or have low discharge, so they do not support large settlements. The number and location of springs in other regions are not known.

Although over 84% of the groundwater abstracted in Ghana is used for drinking and domestic purposes, there is increasing use for irrigation and livestock watering in specific areas. The amount actually irrigated is not known, but the total irrigation potential from boreholes and hand-dug wells is estimated to be over 200,000 ha (Obuobie and Barry forthcoming). Groundwater use for livestock is restricted to the Upper, Northern and the Greater Accra Regions. In the Upper and Northern Regions, troughs are constructed close to boreholes to collect water spilling over them for use by livestock. About 70% of Ghana's livestock are raised in these regions and are watered exclusively using groundwater.

Current groundwater withdrawals in the Volta Basin are not high. Nationally, annual abstractions are estimated at around 271 Mm^3 (130 Mm^3 from hand-dug wells and 141 Mm^3 from boreholes) (Obuobie and Barry forthcoming).

Planned

The rate of construction of wells in Ghana is approaching 1,000 per year and this is likely to increase as population rises (Barry et al. 2005). Because of both scarcity and water-quality issues with surface water, groundwater will continue to be the main source of water supply for many rural communities. Meeting the MDG target of 78% coverage for water supply will require significant investment in well development for rural areas. Urban areas will continue to be serviced mainly from surface water supplies since most large urban centers are on rivers.

Ghana's Growth and Poverty Reduction Strategy 2006-2009 (GRSP II) targeted development and exploitation of groundwater sources for irrigation as a priority. Pilot irrigation projects using groundwater carried out in the Accra Plain by the Water Resources Research Institute realized high yields. Plans have been proposed to extract the large volumes of groundwater needed for irrigation using hydro-fracturing techniques and clusters of 20 to 30 large-diameter boreholes in fractured zone aquifers (Kortatsi 1994).

Soil Moisture

Current

Low-input technologies and SWC practices are currently applied by some Ghanaian farmers to reduce erosion, improve fertility, and increase retention of soil moisture. These include soil structure/soil fertility improvement measures (mulching, cover cropping and contour vegetative barriers) and runoff/erosion control measures (ridge-furrow systems, stone lines, tied-ridging and contour bunds). The large-scale adoption of these practices has been limited by many factors, including insecure land tenure, difficulties in accessing credit, limited knowledge on the extent, impact and costs of land degradation, and on the benefits of SWC practices, and a lack of systematic information on the applicability of such practices to the diverse agroecological zones of Ghana (Diao and Sarpong 2007).

Planned

Ghana's Growth and Poverty Reduction Strategy (GPRS II) (2006-2009) (NDPC 2005) and the Food and Agriculture Sector Development Policy (FASDEP II) (MOFA 2007) both recognize the importance of restoring degraded environments, including measures to stem land and water degradation and increase in-soil water retention capacity. However, there are currently no planned large-scale interventions within the basin. All initiatives are small-scale and either community- or NGO-led.

Wetlands

Current

Wetland ecosystems in Ghana constitute about 10% of the country's total land surface though the majority are coastal (brackish) wetlands. Inland wetlands include permanent freshwater lakes (e.g., Bosumtwi); a freshwater swamp forest (e.g., Amansuri); freshwater marshes along the Black, Red and White Volta; and seasonal swamps and wetlands in valley bottoms of inland streams.

Land use activities common to all wetlands, but in varying intensities, include farming, grazing, housing development, fishing, and fish processing. There is continuous pressure on wetland vegetation for fuelwood and building materials. Other common land use activities include livestock-raising, clay mining, hunting, and some sand mining. Most of Ghana's wetlands have suffered some form of degradation resulting from these activities. The Government of Ghana adopted a National Wetlands Conservation Strategy in 1999.

Inland valley wetlands are estimated to comprise between 8% and 28% of the geographic area of sub-Saharan West Africa (Thenkabail et al. 2000), with up to 1.1 Mha in Ghana, most commonly in the Northern Region (Dekuku et al. 1993). Traditionally, a slash-and-burn farming system is established on the uplands, while the valley bottoms are cultivated for rice (Yiridoe et al. 2006). In some, small earth dams, sometimes fitted with concrete spillways, are used to retain and redirect wet-season flows. These areas are sometimes known as "equipped wetlands."

It is estimated that only 15% of inland valleys in Ghana are currently being cultivated due to various constraints, including insecure land tenure, difficulty in developing and working the land, and health risks from water-related diseases (Gumma et al. 2009). Dekuku et al. (1993) estimated that around 8,224 ha in inland valleys were under cultivation in 1990 (around 3,200 ha within the Volta Basin), with a mixture of rice and vegetables. The National Rice Strategy estimated that there were 92,000 ha of rain-fed lowland rice in 2008, with around 70% of production in inland valleys in the Northern and Volta Regions and UER (MOFA 2009). There are reports that inland valleys are coming under increasing use for cultivation, sometimes resulting in water pollution downstream (FAO 2005b).

Planned

Attaining self-sufficiency in rice production is an important goal for Ghana. In 2005, Ghana's milled rice deficit stood at 0.2 million tonnes (Mt). Under the National Rice Strategy, Ghana aims to increase total rice production from 0.3 to 1.5 Mt by 2018. It is intended that at least 60% of this production should come from increases in rain-fed rice in the lowlands and inland valleys, with an increase in area to 300,000 ha nationally. Major projects to promote rice production in inland valleys are proposed with funding from JICA (Sustainable Development of Rain-fed Lowland Rice Production), AfDB (Inland Valley Rice Development Project) and IFAD (Northern Rural Growth Program). Ghana's Growth and Poverty Reduction Strategy 2006-2009 (GRSP II) promotes the development of small-scale community-based valley-bottom (equipped wetland) irrigation schemes.

DISCUSSION

In many ways, Ethiopia and Ghana face similar problems in developing storage within the Abay and Volta basins, respectively. Both have, on average, moderate rainfall (1,320 vs 1,420 mm) but short intense wet seasons and long dry seasons (6-7 months), with a deficit of rainfall relative to potential evaporation over much of the year and high interannual variability. Both have dispersed rural populations with a high dependence on rain-fed agriculture, high poverty rates and significant food insecurity (higher in Ethiopia), which they plan to address through development of large areas of irrigated agriculture. Both countries have rapidly growing power demands, high dependence on hydroelectricity (more so in Ethiopia) and ambitious plans for hydropower development. It is not surprising that similar solutions have developed in the two countries.

Large reservoirs form the centerpiece of development plans for both the Abay and Volta basins. Very substantial investments are proposed for hydropower and irrigation infrastructure, either separately or as multipurpose schemes. In both basins, existing large dams were built primarily for hydropower but many of those planned are intended to provide both hydropower and irrigation. In both basins there is considerable potential for increasing irrigation. In the Abay there is almost no experience of large-scale irrigation, but elsewhere in the country schemes have largely been well-managed (by parastatals) and have been shown to make a significant contribution to agricultural GDP and livelihoods. This contrasts with Ghana, where returns from large-scale irrigation have generally been much lower than expected, with serious problems of operation and maintenance, compounded by farming communities without the knowledge or technical support to use available irrigation effectively. The Koga irrigation scheme in the Abay is the first in Ethiopia that will be farmer-managed and it remains to be seen whether or not it is successful. Studies have repeatedly shown that large dams have a range of both positive and negative impacts on local communities. Individual projects must be assessed very carefully prior to construction to ensure that they are not only economically viable but also environmentally and socially acceptable.

Groundwater is the major source for domestic and household supplies in rural areas, accounting for more than 75% of rural supply in Ethiopia and between 50% and 70% in Ghana. Groundwater is usually accessed using hand-dug wells and shallow boreholes. In the Volta, shallow but low-yielding weathered zone aquifers are a major source in the drier areas of the north. These can be frequently accessed using hand-dug wells, but are subject to seasonal fluctuations. Shallow boreholes accessing fractured zone aquifers are more expensive but generally more reliable with somewhat higher, but still low, yields. In the Abay, hand-dug wells are restricted mainly to alluvial aquifers. Away from river systems, boreholes are needed to access groundwater at depths averaging 30-100 m. Springs are a common water source in the highlands, but may fluctuate seasonally. Deep boreholes are not common in the rural areas in either basin. In the Volta, there is no advantage in deep drilling, since yields are no higher. In the Abay, deep boreholes are used mainly for urban and industrial supplies. They can access high-yielding aquifers, but costs are high and siting difficult in the absence of detailed hydrogeological knowledge.

In both basins, current groundwater abstractions are only a very small fraction of total basin recharge. Withdrawals are limited more by extraction technologies than by aquifer yield. Potential exists for the development of groundwater irrigation but with some caveats. In the Volta, the preponderance of low-yielding shallow aquifers means that opportunities to extract the high volumes needed for large-scale irrigation may be limited, particularly in fractured zone aquifers with low permeability. It is generally considered that a flow of 2 ls^{-1} is needed to irrigate 1 ha. In much of the Volta Basin, yields are lower than this. In the Abay, the prospects for groundwater irrigation are better, since yields are generally higher and relatively shallow boreholes can access regional aquifers with much higher storage.

Rainwater harvesting and storage in tanks or ponds (dugouts in Ghana) are important components of household supply, as well as providing water for livestock and gardens. In the Volta, small household tanks (5-10 m^3) collecting water from roofs are common. In the Abay, larger communal systems are more common, with construction of lined ponds or underground tanks storing up to 60 m^3. While the potential for rainwater harvesting is apparent in both basins, the success or failure of various rainwater harvesting technologies depends on a complex set of technical and social considerations, and schemes need to be planned in consultation with communities, drawing on the now considerable experience from previous projects. Open ponds have high evaporative losses and increase the incidence of water-related diseases, but covered or underground tanks are technically more complex and expensive.

In the Volta, particularly in the north, small earth reservoirs are very common for community water supplies and for agriculture. Similar to ponds, they suffer from the same disadvantages of high evaporation and potential negative health impacts. However, the large numbers in northern Ghana indicate that communities find them useful, even though many dry out during the dry season. Although small reservoirs are not common in the Abay Basin now, they may become so in the future.

The SWC techniques have been implemented much more extensively in the Abay than in the Volta, due largely to the urgency of erosion problems in the Ethiopian highlands and government policies that promote FFW schemes. Techniques such as traditional bunds, ridge-furrow systems and the use of micro-catchments have all shown benefits in terms of off-site impacts, but production benefits have been more difficult to demonstrate. Widespread adoption of these techniques is hindered by a variety of constraints, not least of which is the fragmentation of landholdings. Very substantial investment in agricultural extension and education, and possibly the introduction of incentive systems (e.g., payment for environmental services) are required.

Wetland agriculture is considered to have high potential in the Volta, where government plans explicitly target the use of inland valleys for agriculture. Currently only about 15% of inland valleys are used but up to 1 Mha may be suitable for rice production. In the Abay, where livestock generally make a greater contribution to livelihoods, wetlands play a very important role in supporting dry-season grazing. Currently, they are not specifically targeted for agricultural development but rising population and increased upland degradation are increasing pressure on them. In both basins, utilization of wetlands for agriculture should be integrated within basin management plans. The long-term environmental consequences and the potential loss of important ecosystem services should be carefully considered.

CONCLUDING REMARKS

Water storage, in a variety of forms, is vital for the well-being and livelihoods of the people living in the Volta and the Abay river basins. Simultaneously, the development of water resources in these basins, including water storage, is central to the economic development of Ghana and Ethiopia. However, despite its recognized importance, this study has highlighted the lack of knowledge and information on both existing and planned storage. For both basins, basic understanding (e.g., on groundwater availability and recharge) is insufficient or simply lacking. In both cases, data and information for a range of storage types are unavailable or dispersed and difficult to access. With the exception of large dams, past storage development has occurred in a piecemeal fashion, largely through local initiatives and with minimal planning. In some cases (e.g., where reservoirs have silted, wells are dry and ponds have aggravated negative health impacts), it is clear that the lack of both information and planning has resulted in less-than-optimal investments.

Future population growth, in conjunction with climate change, will increase the importance of water storage in both basins. However, as water resources are increasingly utilized and climate variability increases, planning will become ever more difficult. Without greater understanding of which types of storage are best utilized under specific agroecological and social conditions, and in the absence of much more integrated planning, it is probable that many water storage investments will fail to deliver intended benefits. In some cases they may even worsen the negative impacts of climate change.

To ensure successful future water storage development within both basins much greater integrated planning than in the past is required. The following would usefully contribute to this end:

- Standardized approaches for mapping and inventorying existing storage in all its forms.
- Development of systematic methods for evaluating storage performance (i.e., suitability and effectiveness) across the range of environmental and socioeconomic conditions found in each basin and for the variety of storage options.
- Creation of a basin water storage development strategy consistent with any basin master plan and clear identification of objectives and priorities for investment in all water storage options, not just in large dams.
- Enhanced research to better understand water resources and storage in both basins (including mapping of aquifers; groundwater-surface water interactions; potential climate change impacts on water supply and demand; the social and environmental impacts of different storage options and the implications of scaling-up small-scale interventions; and the reasons for success/failure of past storage schemes).
- Clearly articulated environmental and social safeguards that minimize potential adverse impacts (including health) for all storage options.

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